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Fluid Systems Div of UOP, Inc, San Diego, CA

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REVERSE OSMOSIS RENOVATION OF SECONDARY EFFLUENT

by

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Grant #802004

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16. ABSTRACT

A demonstration of the performance and economics of reverse osmosis treatment of municipal secondary effluent on a sufficient scale to project large plant costs was attempted. The desalted effluent was blended with additional secondary effluent and used for irrigation through an existing irrigation system. A plastic-lined evaporation pond was constructed for brine disposal during the project.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This report covers a demonstration of reverse osmosis renovation of secondary effluent at the Southside Water Reclamation Facility of the City of Escondido, California.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

The purpose of this study was an effort to demonstrate the performance and economic value of reverse osmosis processing of municipal effluents on a sufficient scale to predict large plant operation costs. A secondary purpose was the use of renovated demineralized secondary effluent to prevent an adverse salt balance in the Lake Hodges basin near Escondido, California.

The program which was carried out under EPA Grant #802004 included the construction and operation of a 6.57 x $10^{-3}m^3$/sec (150,000 gpd) reverse osmosis system which processed a portion of the secondary effluent produced at the Southside Water Reclamation Facility, Escondido, California. Although the study was severely limited by pump problems, and high levels of turbidity and suspended solids, the operational costs incurred were consistent with similar and much larger reverse osmosis systems operating on secondary effluent. Laboratory analysis of the reverse osmosis product water indicated excellent solute reduction (91-94% TDS rejection at 2.75 Mpa (400 psi) with 75% recovery based on feed) and this water could be applied to the ground for recharge.

This report was submitted in fulfillment of Grant #802004 by Fluid Systems Division of UOP, Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period July 15, 1973, to May 31, 1977, and work was completed as of August 29, 1977.

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Introduction

This is the final report on work performed by Fluid Systems Division of UOP, Inc. under Environmental Protection Agency Grant #802004, "Reverse Osmosis Renovation of Secondary Effluent", during the period June 1, 1975 to June 1, 1977. This study of reverse osmosis renovation of secondary effluent which was performed at the Southside Water Reclamation Facility (Escondido, California), was primarily funded by a federal demonstration grant program; and was a joint venture between the United States Environmental Protection Agency, the City of Escondido, California, the City of San Diego, California, and Fluid Systems Division of UOP, Inc.

Project Objectives

The major objectives of the program were to demonstrate:

1) The performance and economics of reverse osmosis processing of municipal effluents on a sufficient scale to project large plant costs with confidence.

2) The use of renovated, demineralized secondary effluent to prevent an adverse salt balance in the Lake Hodges basin.

The pilot test programs at Pomona under EPA contract #14-12-831 indicated the technical feasibility of reverse osmosis treatment of secondary effluents using spiral wound elements. In order to scale results to future systems of 0.044 - 4.4 m^3/sec*, the techniques had to be demonstrated on a larger scale. The test unit for these studies had to be large enough to be free from artificial constraints such as recirculation. It also had to be of sufficient size

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* See Appendix A for Conversion Values

to develop cost and performance data that could be validly extrapolated to predict operating costs in a municipal system. Coupling these requirements with the need to operate at high recovery rates to minimize concentrate volume indicated the necessity of a reverse osmosis pilot plant of $4.38 - 8.76 \times 10^{-3} m^3/sec$ product water capacity. The unit would have to be operated for at least two years to confirm membrane lifetime and performance predictions.

A reverse osmosis unit of this size was needed to reduce the total dissolved solids content of the secondary effluent from the City of Escondido Southside Water Reclamation Facility. This effluent must be reduced in salinity before application to the ground, because ground water salinity in the basin where the plant is located is at an unacceptably high level.

Pilot Plant Location

The reverse osmosis pilot plant is located at the Southside Water Reclamation Facility, a $1.3 \times 10^{-2} m^3/sec$, contact-stabilization activated - sludge treatment plant located south of Escondido, California, near Interstate Highway 15 (See Fig. 1).

During the course of this study, this treatment plant was operating 24 hours/day. The plant was treating a portion of the sewage flow from Rancho Bernardo (a part of the City of San Diego lying south of Escondido). The secondary effluent is used for irrigation in two areas near the plant labeled (A) and (B) on Figure 1. After percolation, the water eventually reaches Lake Hodges, which is one of the reservoirs of the City of San Diego water supply.

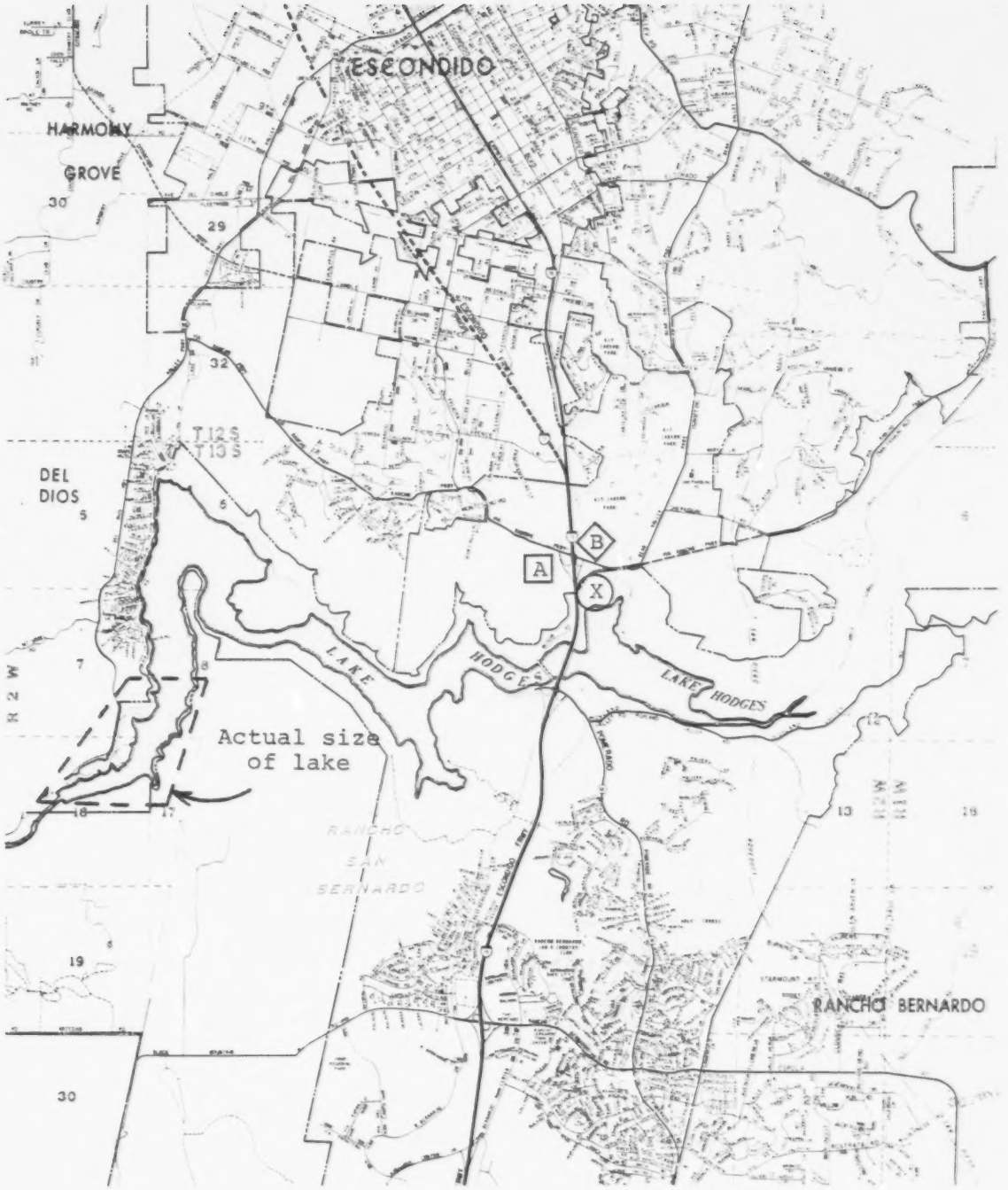

Fig. 1 - Location of the Reverse Osmosis Pilot Plant- X

Location of Irrigation Ponds - A & B

In recent years, the salinity of Lake Hodges and the San Pasqual Valley has reached very high levels. Table 1 shows a typical chemical analysis of Lake Hodges and Judson Well, located upstream and east of the lake in the San Pasqual Valley. Salinity levels of the influent and effluent of the Southside Water Reclamation Plant are also very high. Table 2 indicates a composite chemical analysis of the Southside Plant which shows the total dissolved solids (TDS) content in the effluent to range from 1380 to 1516 mg/l. It is apparent that conditions in the Lake Hodges area will continue to deteriorate if the effluent from the Southside treatment facility is applied to that basin. However, it was envisioned that if roughly one-half of the effluent was reduced in total dissolved solids content 90-95% using reverse osmosis, the combined blended effluent would range from 725-834 mg/l total dissolved solids. This would be an important step toward a solution of the problem. Of course, it is obvious that much more desalination would be required to significantly reduce to total dissolved solids content of Lake Hodges.

Reverse Osmosis System Description

Figs. 2-3 show a schematic flow diagram of the reverse osmosis system. The system was designed to produce $6.57 \times 10^{-3} m^3/sec$ of product water within a normal operating range of 2.07 - 4.13Mpa. No concentrate recycling is required with this reverse osmosis unit. The unit was designed to have sufficient flexibility of control and capacity to produce from $6.1 - 7.56 \times 10^{-3} m^3/sec$ of permeate from $8.19 - 9.13 \times 10^{-3} m^3/sec$ of secondary effluent at pressures in the range of 2.07 - 4.14 Mpa and at feed temperatures from $15^{o} - 30^{o}C$. This corresponds to a water recovery range of 75-90%.

TABLE I

CHEMICAL ANALYSIS OF WATER FROM THE LAKE HODGES AREA

Constituent	Concentrations (mg/l)	
	Hodges Reservoir	Judson Well
Calcium Ca	100	121
Magnesium Mg	45	54
Sodium Na	100	108
Potassium K	7.3	4.5
Carbonate CO_3	1.4	0
Bicarbonate HCO_3	292	438
Sulfate SO_4	172	152
Chloride Cl	185	154
Nitrate NO_3	1.01	9.90
Fluoride F	0.30	0.26
Silica SiO_2	7.4	34.7
Iron Fe	0.02	0.03
Manganese Mn	0.10	0.38
Phosphate PO_4	0.14	0.04
Aluminum Al	0.03	0.01
TDS	921	1,096
Total Hardness	436	527
Carbonate Hardness	242	354
pH	8.2	7.6

TABLE 2

Composite Chemical Analysis of the Secondary Effluent
from the South Side Treatment Facility

Constituent	Concentration (mg/l) (a)	
	Average (b) Value	Range
Calcium Ca	107	92-124
Magnesium Mg	44	36-56
Sodium Na	310	304-320
Potassium K	13	12-13
Ammonia NH_4	9	2.5-13
Hydroxide OH	0	0
Carbonate CO_3	0	0
Bicarbonate HCO_3	203	189-231
Sulfate SO_4	400	382-433
Chloride Cl	379	361-386
Nitrate NO_3	37	23-53
Silica SiO_2	38	22-56
Iron Fe	0.28	0.05-0.72
Manganese Mn	0	0
Ortho Phosphate PO_4	24	18-30
Nitrate NO_3	8.5	5.2-9.8
Ammonia NH_4	6.5	1.9-9.7
Alkalinity $CaCO_3$	166	155-190
Hardness $CaCO_3$	448	425-460
TDS	1,465	1,380-1,516
BOD	18.3	9.3-41
COD	58	27-115
Conductivity umhos @ 25°C	2,328	2,260-2,370
pH	7.55	7.23-8.05

a) before Cl_2 addition

b) based on four samples

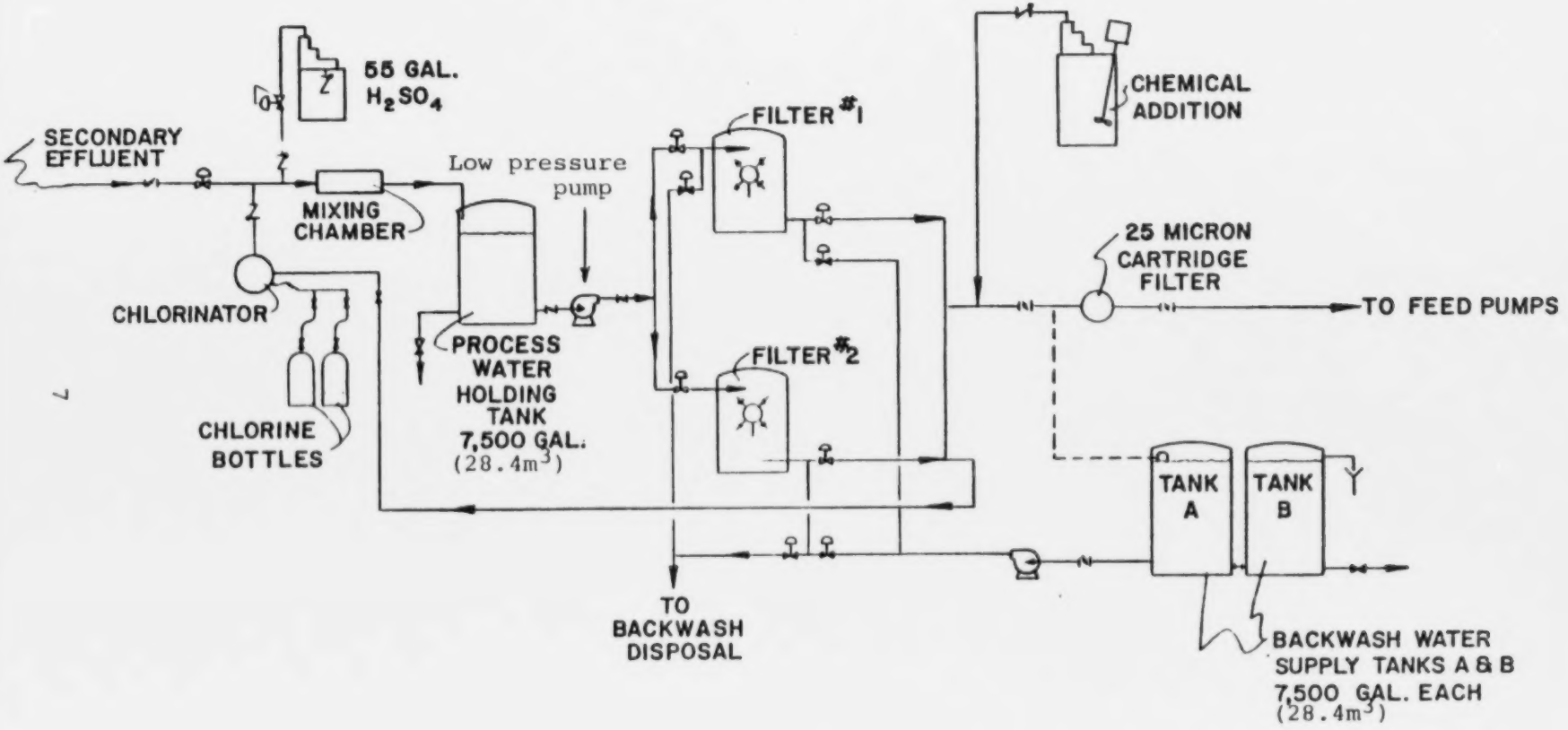

Fig. 2 Escondido Unit - Pretreatment Flow Diagram

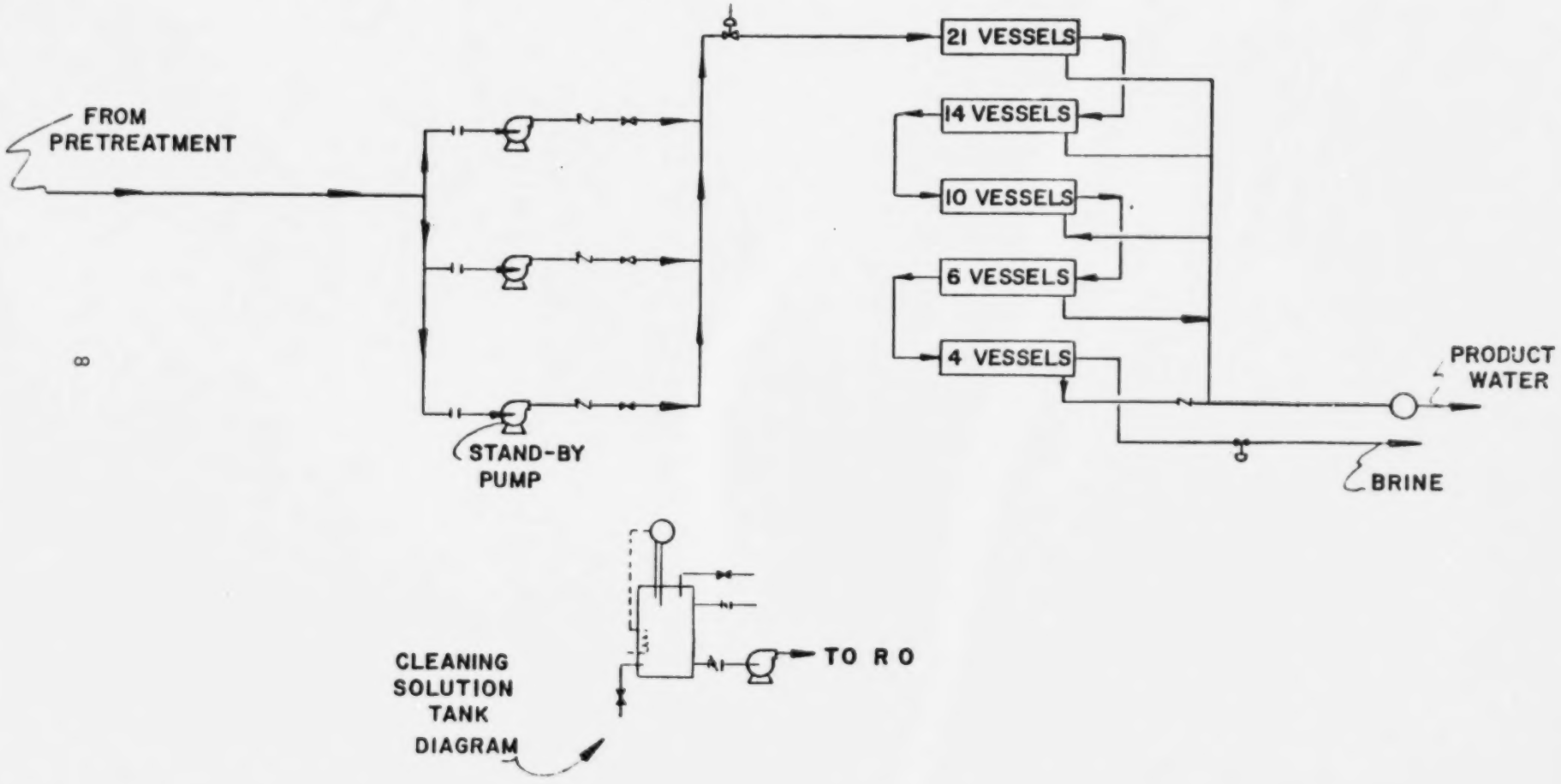

Fig. 3 Escondido Unit - Reverse Osmosis Flow Diagram

Throughout the course of the study, approximately $8.82 \times 10^{-3} m^3/sec$ of secondary effluent from the Southside Reclamation Plant was transferred to the $28.4 m^3$ FRP process water holding tank by a centrifugal booster pump before being processed by the reverse osmosis system. Just prior to the process water holding tank, the feed water is acidified (pH 5.0-6.0) with H_2SO_4, chlorinated (0.5-1.5 mg/l with Cl_2), and mixed by an in-line static mixing chamber. Both acidification and chlorination are controlled by automatic injection systems. Fig. 2 is a diagram of the pretreatment system.

After a retention time of approximately 50 minutes in the process water holding tank, the feed water is transferred by another centrifugal booster pump, through a set of twin, automatic, dual media pressure filters. The feed water is screened further through a 25 micron cartridge filter before entering the high pressure feed pumps that supply the RO unit. Between the dual media filters and the cartridge filter bank, the feed water is injected with a scale inhibitor-sodium hexametaphosphate at the rate of 5 mg/l.

The dual media sand filters (anthracite and sand) are each 1.83m in diameter with a media surface area of approximately $2.6 m^2$, and operate in parallel during normal operation processing. At peak flow, each filter receives approximately $4.6 \times 10^{-3} m^3/sec$ of feed water, or $1.765 \times 10^{-3} m/sec$* of media surface area. Normally, the Fluid Systems' staff recommends a flow rate of approximately $3.4 - 3.74 \times 10^{-3} m/sec$** of media surface area on surface waters and similar applications; however, the filters on this unit were purposely over-sized to accommodate higher than normal suspended solids loading that usually accompanies secondary effluent.

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* $1.765 \times 10^{-3} m^3/sec$ per m^2

** $3.4 - 3.74 \times 10^{-3} m^3/sec$ per m^2

Backwashing of the media sand filters could be initiated in one of three ways:

1. Manually, be depressing the manual "start" push button.
2. Automatically by time clock.
3. Automatically by differential pressure.

For this study on secondary effluent, method number 3 was chosen because of the unpredictable nature of the feed water in regard to suspended solids loading and its effect on differential pressure. Immediately following backwash, differential pressure across the media filters is approximately 27.6-31Kpa. The automatic controls will initiate a backwash at 103.4Kpa differential pressure.

During the backwash cycle, the entire feed stream is switched to one filter while the other filter is backwashed. During this cycle, the flow rate through the in-service filter is approximately 3.53×10^{-3}m/sec* of filter surface area.

The filters are backwashed with media filter effluent that has been stored in two additional 28.4m^3 backwash water storage tanks. The 30-minute (each) filter backwash cycle, includes an air-scrub (5 minutes), a backward rinse at a flow rate of approximately 6.79×10^{-3}m/sec** of media surface area or $1.76 \times 10^{-2}m^3$/sec (10 minutes) and a forward rinse of approximately $5.29 \times 10^{-3}m^3$/sec with sand filter influent. After each backwash cycle, the backwash water supply tanks are automatically recharged with sand filter effluent, a total of approximately 21.2m^3.

The reverse osmosis unit consists of 55, 10.16cm x 6.096m specially epoxy-coated carbon steel pressure vessels capable of

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* $3.53 \times 10^{-3}m^3$/sec per m^2

** $6.79 \times 10^{-3}m^3$/sec per m^2

accomodating 6, 10.16cm x 1.02m spiral wound ROGA reverse osmosis elements each. The vessels are arranged in a series of five passes so that concentrate from one pass becomes feed water for the next. As noted in Figure 3, the passes contain 21, 14, 10, 6 and 4 vessels from feed to concentrate end respectively.

Product water from each of the individual passes is collected in a common product water header or manifold and transferred back to the Escondido Southside Reclamation Plant for blending with the untreated secondary effluent that is then discharged to the holding ponds for irrigation purposes.

Each pass of the RO unit is equipped with sample valving that allows individual quality measurements to be taken. In addition, the unit is equipped with a 0 to 0.69Mpa differential pressure measuring system for measuring the ΔP across the entire unit or each of the individual passes.

The unit is also equipped with a built-in cleaning system that includes a 1.893 m^3 heated batch tank, and the necessary plumbing and valving for cleaning the entire unit or each pass individually. The cleaning system is also used for preserving the unit (membrane) with 0.65% formaldehyde and for periodically measuring the product water flow rate in calibration of the instruments. Product water is normally used for cleaning the RO system.

A main feed valve located in the feed line between the high pressure feed pumps and the first pass of the RO system, controls feed flow and pressure to the unit. The valve is automatically regulated by a product water sensor and controller system that maintains a constant, pre-set product water output.

A brine flow regulating and back pressure valve is also tied into the automatic system. Thus, the product water of the unit output and recovery are maintained at a steady rate by the automatically controlled regulating system. Only the feed pressure is varied.

In addition to those controls and instruments described on the previous page, plus the usual safety devices such as alarms and safety switches, the unit is equipped with the following instrumentation:

1. Turbidimeter
   In-line, Hach Surface Scatter III, Monitor and Recorder; Monitors and Records Feed Water Turbidity
2. pH Monitors and Recorders
   Monitor and Record the Secondary Effluent pH, the pH of the Effluent after H_2SO_4 Injection, and pH of the Feed Water to the RO Unit.
3. Chlorine Monitor and Recorder
   Monitors and Records Cl_2 content of the product water.
4. Pressure Gauge, Sensors and Recorders
   Monitors and Records Feed Pressure to the Unit
5. Product and Concentrate Flow Recorders
   Self-explanatory
6. Feed and Total Product Conductivity Monitors and Recorders - Self Explanatory

The unit is fed by three (one standby) single stage, high pressure, centrifugal pumps, each with a rated output capacity of $4.62 \times 10^{-3} m^3/sec$ at a discharge pressure of 4.47 Mpa. Figs. 4-13 show photographs of various areas that compose the RO processing system.

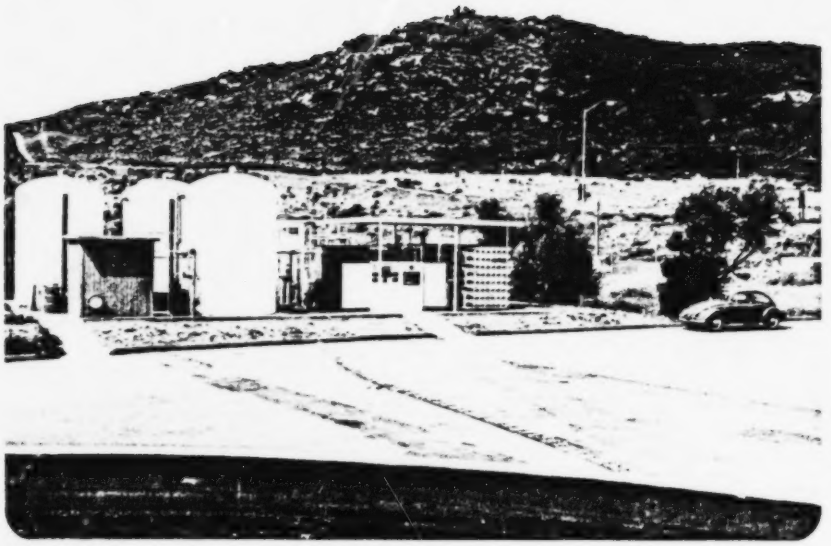

Fig. 4 Escondido Secondary Effluent Reverse Osmosis System

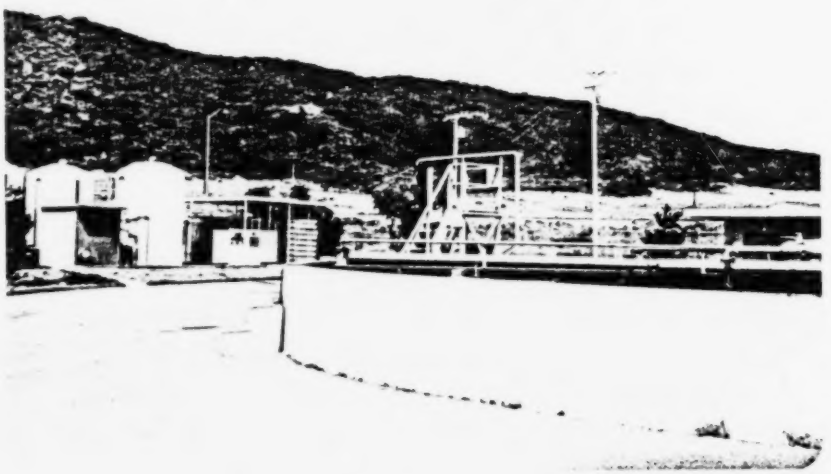

Fig. 5 View of RO System with the Southside Treatment Plant in foreground

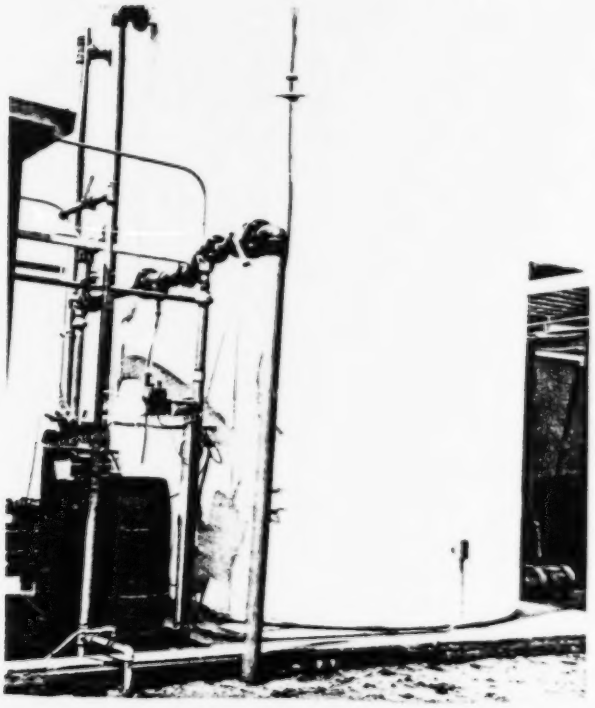

Fig. 6 Process Water Holding Tank and associated acid and Cl_2 addition piping

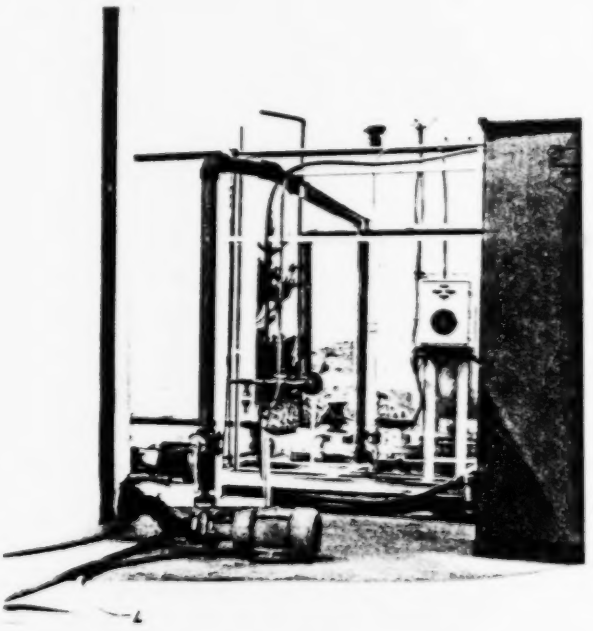

Fig. 7 Centrifugal Booster pump from the Process Water Holding Tank that feeds sand filters in background

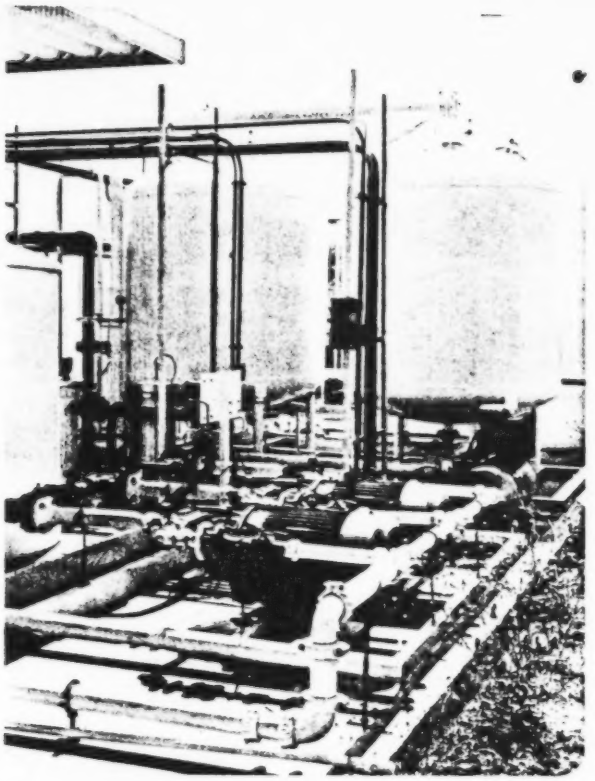

Fig. 8 High-pressure feed pumps with sand filters in background

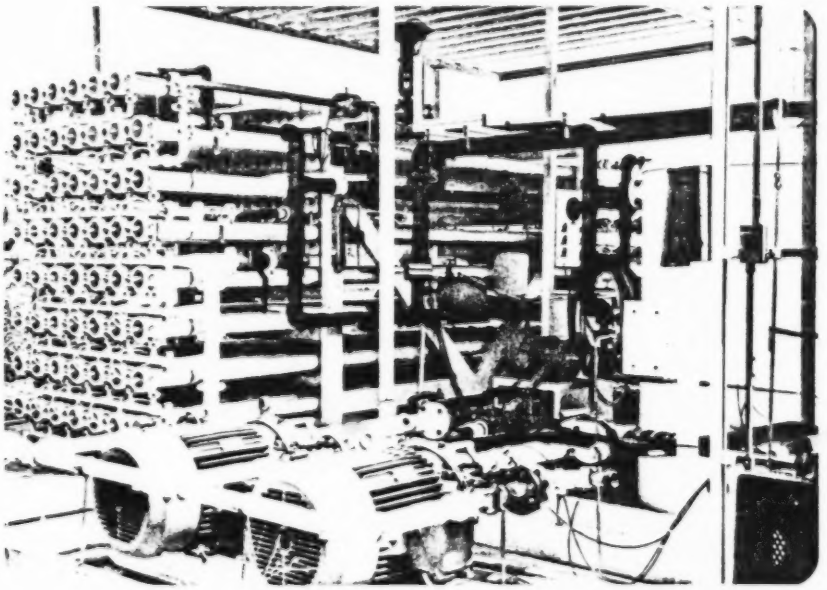

Fig. 9 Pressure Vessel Assembly. Element cleaning loop storage tank and cleaning pump is shown at right

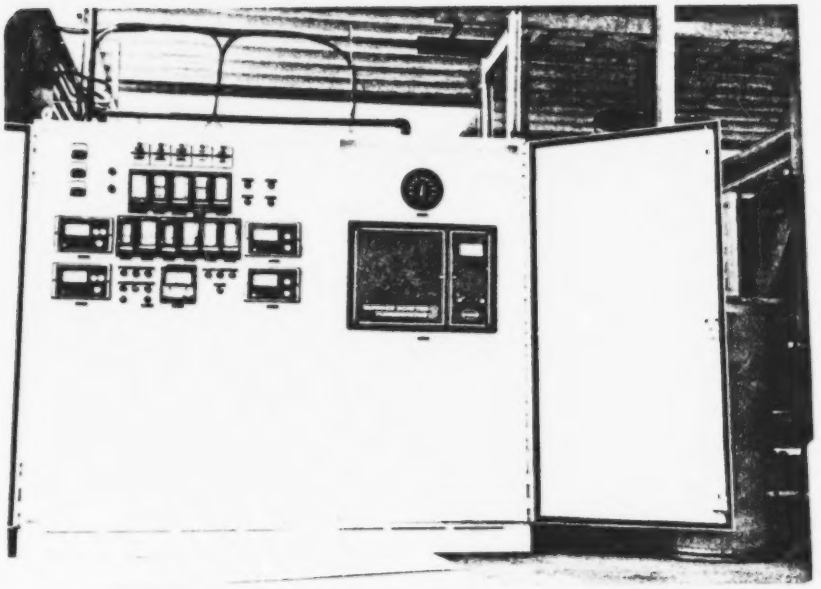

Fig. 10 RO System Control Panel

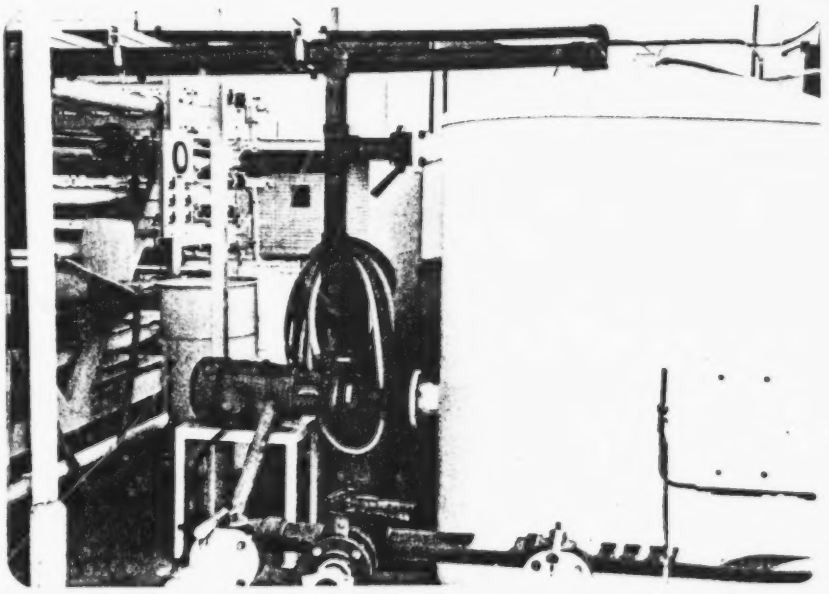

Fig. 11 View of element-cleaning loop storage tank, cleaning pump, and piping

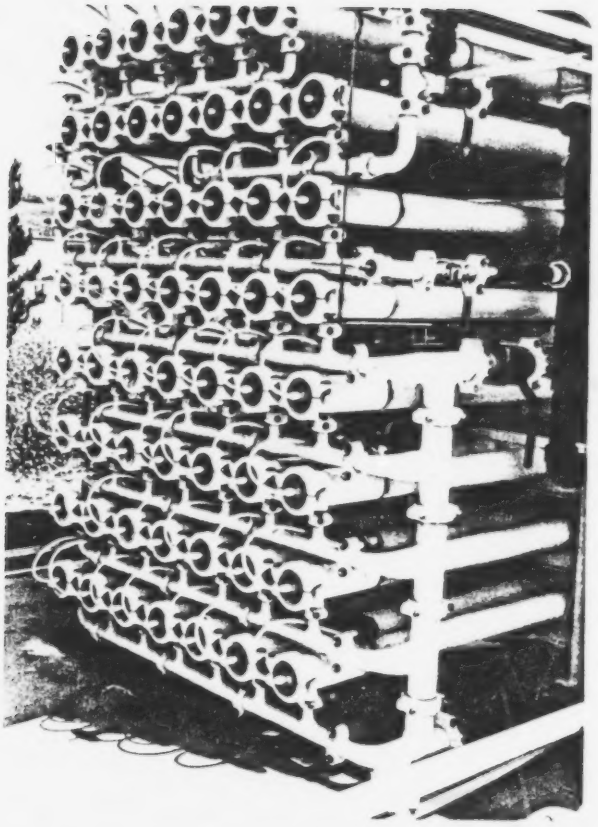

Fig. 12 Pressure Vessel Assembly - end view, product water manifolds

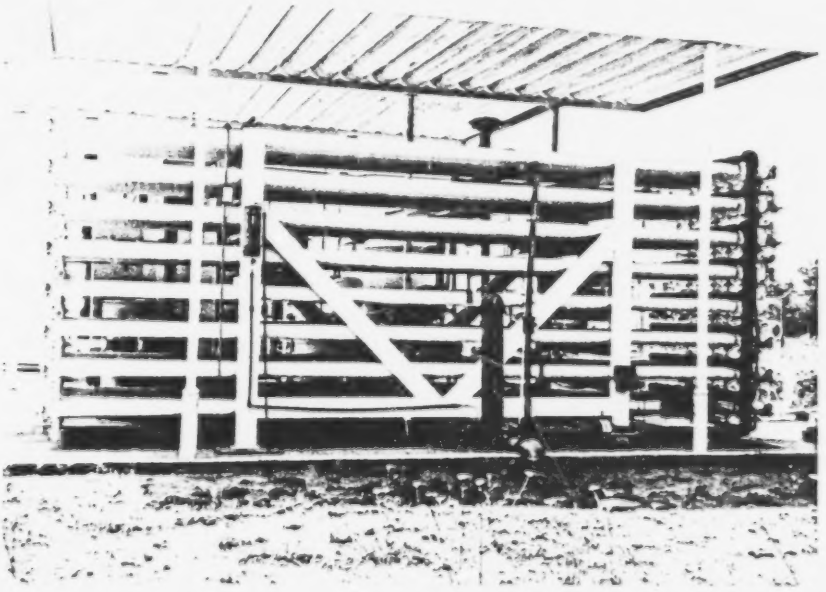

Fig. 13 Reverse Osmosis Pressure Vessel Assembly - Side View

Mechanical Complications

Due to mechanical problems, mainly numerous failures of the high pressure RO feed pumps, the Escondido RO system was operated on a very limited basis between June 1, 1975 and February 12, 1976. To a lesser degree, other complications such as mechanical problems of a less serious nature, and the lack of clear cut operational and contractual guidelines also hampered operation of the system. In summation, down time attributable to the RO feed pump failures is estimated at approximately 80% of the total available running hours during the aforementioned time span.

Pump failure in the form of destroyed bearings in the high speed shaft assemblies of the high speed, single stage pumps occurred twice during the initial start-up phase of the program. After each failure, the manufacturer was consulted, and the failures were attributed, by him, to the start-up and operational procedures of the pumps and system.

On July 31, 1975, at the request of Fluid Systems, a manufacturers representative (product specialist) visited the site. After going through numerous start-ups, he made a number of requests for changes in the start-up procedure--all of which were immediately and readily complied with by Fluid Systems. During the visit, a leak in one of the pumps, thought to be a seal leak, was pointed out to the representative. He assured the Fluid Systems personnel that it should be of no concern, as it would probably seal itself in a short period of time. Shortly thereafter, that pump failed. Again, the manufacturer cited the start-up procedure as the probable cause.

On August 19, 1975, again at the request of the Fluid Systems staff, another representative visited the site to checkout the start-up and operation procedure. In addition, he witnessed repair (replacement of a high-speed shift assembly) of a failed pump by Fluid Systems technicians. After going through a start-up, the representative pointed out some major discrepancies in the start-up procedure that would, beyond any doubt, result in bearing damage to the pumps. He immediately recommended major changes in the start-up procedure--most of which were in direct conflict with the instructions given previously by the other representative on July 31, 1975. After numerous start-up trials, he approved of the manner in which the pumps were operated. However, during the next 90 to 120 days, the pumps continued to fail at least twice more. Over the entire time span described above, parts were shuttled to and from the manufacturer in an attempt to diagnose the problem and at the same time log as much system running time as was possible. This, of course, had to be primarily at Fluid Systems' expense as it was necessary to keep a Fluid Systems representative on site almost full time.

By mutual agreement between all of the parties involved, all three of the pumps, in their entirety including motors, were removed during the last part of November, 1975 and shipped back to the factory for a complete analyses and refurbishment. They were repaired and tested for a minimum of 100 hours before being shipped back to Fluid Systems about January 1, 1976. The repair work was covered by the manufacturer and a new warranty was given. Due to a number of unforeseen complications, such as parts that were damaged upon removal, parts that had to be specially ordered for replacement, and absence of the operator (employee of City of San Diego) for jury duty, the system was out of service until February 12, 1976.

From February 12, 1976, through June 8, 1976, the high-pressure pumps were subjected to numerous start-ups while the system was being operated on a day run basis and all total logged an additional 275 hours of running without any detectable mechanical problems. Later on in the study, however, 78 additional operating days were lost due to problems with the high pressure pumps.

The exact cause of all of these pump problems is still unknown, however, it is generally felt that these pump problems were caused by improper initial start-up procedures or by some inferior part within the pumps that has caused some excessive wear and/or damage to other pump components, resulting in failures. Only two of the three pumps at the site have experienced these problems and both pumps and motors have consecutive serial numbers which may indicate a manufacturing malfunction. Meanwhile, the other high pressure pump was operated without difficulty. Some consideration was given to switching to another pumping system, however, this idea was laid to rest due to the high cost of the equipment and system modification as well as the associated down time. A decision was made to complete the remainder of the study with the existing high pressure pumps.

Table 3 shows the history of the downtime attributed to the high pressure pumps.

The elements used for the Escondido Study were Fluid Systems' type 4101 CA element. Membrane used for these elements uses an acetone-formamide casting solution with approximately 20% Eastman 400-25 cellulose acetate polymer. The membrane is annealed at 80-85^{o}C.

TABLE 3 History of Pump Downtime

Dates	Down time	Cause
8-28-75 to 10-21-75	54 days	High speed pump bearings
6-9-76 to 6-23-76	14 days	Oil seals in pump motors
8-11-76 to 10-14-76	64 days	Motor shafts reworked and pumps checked out and rebuilt

Table 3 also shows that because of pump problems, 132 days of operation were lost, or approximately 22% of the total available days of operation.

Operation and Test Results

As discussed on the previous pages, between June 1, 1975 and June 9, 1976, the system was operated as much as possible between the period of pump failure. Operation was on a day run basis of 4 to 5 hours per day. During all lengthy shut-downs, the media filters were dosed with Clorox to prevent biological growth. They were purged to drain each time prior to the system being placed back in service.

Sand filter performance during the period 1975 - Feb. 1976 is summarized in Table 4. The feed water was evaluated for turbidity at five different points in the pretreatment train. Most of the time three sets of data were taken daily.

The feed water (sand filter effluent) was continuously monitored and recorded with an in-line Hach Surface Scatter III Turbidimeter. For the other readings, as well as for a comparison with the in-line instrument, a Hach portable 2100 turbidimeter was used.

During June, July, and August 1975, only the secondary effluent and the feed water (media filter effluent) were sampled for turbidity to any extent. Later on, sample points were installed before and after the centrifugal booster in an attempt to determine by turbidity evaluations if the booster pump breaks up the weak-acid floc that has been formed in the tank; in most cases, the turbidity change was negligible, but if anything, rose .2 to .3 NTUs* before and after the centri-fugal booster pump.

Table 5 shows some additional information on feed water turbidities for the period after July 1976. In general, turbidity rejection by the sand and cartridge filtration

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* National Turbidity Unit

TABLE 4

Escondido Average Feed Water Turbidities and
Differential Pressures by the Month

1975 - February 1976

	Treatment Plant Secondary Effluent		Sand-Media Filter		
Month	Before Holding Tank*	After Holding Tank*	Before Filter*	After Filter*	Differential Pressure Kpa/hr
June 1975	3.8	---	---	1.2	---
July 1975	4.7	---	---	1.2	10.4
August 1975	3.8	---	---	1.0	11.7
October 1975	4.3	5.4	5.4	1.2	6.9
February 1976	3.6	3.5	3.7	1.5	2.07

* Turbidities in NTUs

TABLE 5

Escondido Average Feed Water Turbidities
After Media and Cartridge Filtration

Date	Average Value Turbidities NTUs	Range Turbidities NTUs
July 1976	0.65	0.40-1.00
October 1976	0.35	0.21-0.58
November 1976	0.75	0.25-3.50*
December 1976	0.30	0.16-0.54
January 1977	0.60	0.20-1.00
February 1977	0.65	0.31-1.50
March 1977	1.10	0.62-1.35
April 1977	1.50	0.27-3.00*
May 1977	0.50	0.30-1.00

* Several periods of high solids content influent to the South Side Plant

units was a function of the turbidity present in the processed secondary effluent. There were days of very low feed turbidity and days of very high turbidity when high solids content was present in the Southside influent. The high turbidity readings recorded in November 1976 and April 1977 was the result of high-solids present in the influent. There were also many short periods of high suspended solids' levels due to improper decanting in the wastewater treatment plant.

Figs. 14 through 19 show plots of normalized permeate water flow to design flow versus time at 75% recovery. Figs. 20 through 25 show plots of normalized permeate water quality to design water quality versus time at 75% recovery. These plots also show a history of significant events during the course of this study.* As can be seen from the data, 2500 hours of actual operation were logged over the 720 days of the study. Mechanical problems, weekend shut-downs, and lack of fail-safe controls in the beginning of the study all contributed to days of little or no RO processing. Most downtime occurred during the first 420 days of the study when only 500 hours of operation was gathered. This time period consisted of most of the downtime attributed to the pump problems; insufficient fail-safe controls and a general lack of confidence in the high-pressure pumps which led to a Monday-Friday operation of the system for approximately 5 hours daily.

The long-standing goal of unattended overnight operation of the reverse osmosis system was finally put into effect on August 2, 1976. This 24 hr./day operation was followed daily through the week with weekend shutdowns, due to the unavailability of weekend operator attention. Overnight operation was accomplished by removing some mechanical problem areas that in the past would allow a situation to develop that would shut down the RO system when unattended. One of these problems would occur when the system would initiate the automatic sand filter backwash cycle.

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* See Appendix B for an interpretation of Figs. 14-25.

A sudden surge of feed water to the forward rinse cycle of the backwash would result in a sharp pressure loss to the high pressure pump causing a shutdown.

This problem was solved by cutting back the water flow to the sand filter during the forward rinse cycle and also increasing the time required during this phase of the backwash cycle. These two changes resulted in the same amount of total forward rinse water to pass the sand filter as before, but with no sudden pressure loss from lack of water to the high pressure pumps.

Another problem that would cause a shutdown after several hours of operation was an automatic feed control valve that was restricting the flow of the secondary effluent from the treatment plant to the 28.4m^3 holding tank. Even in the wide open position, this valve restricted the flow enough so that the demands of the high pressure pumps would not be met. This automatic valve was removed from the system and the flow to the tank was then controlled with full flow valves using a partial overflow of the storage tank.

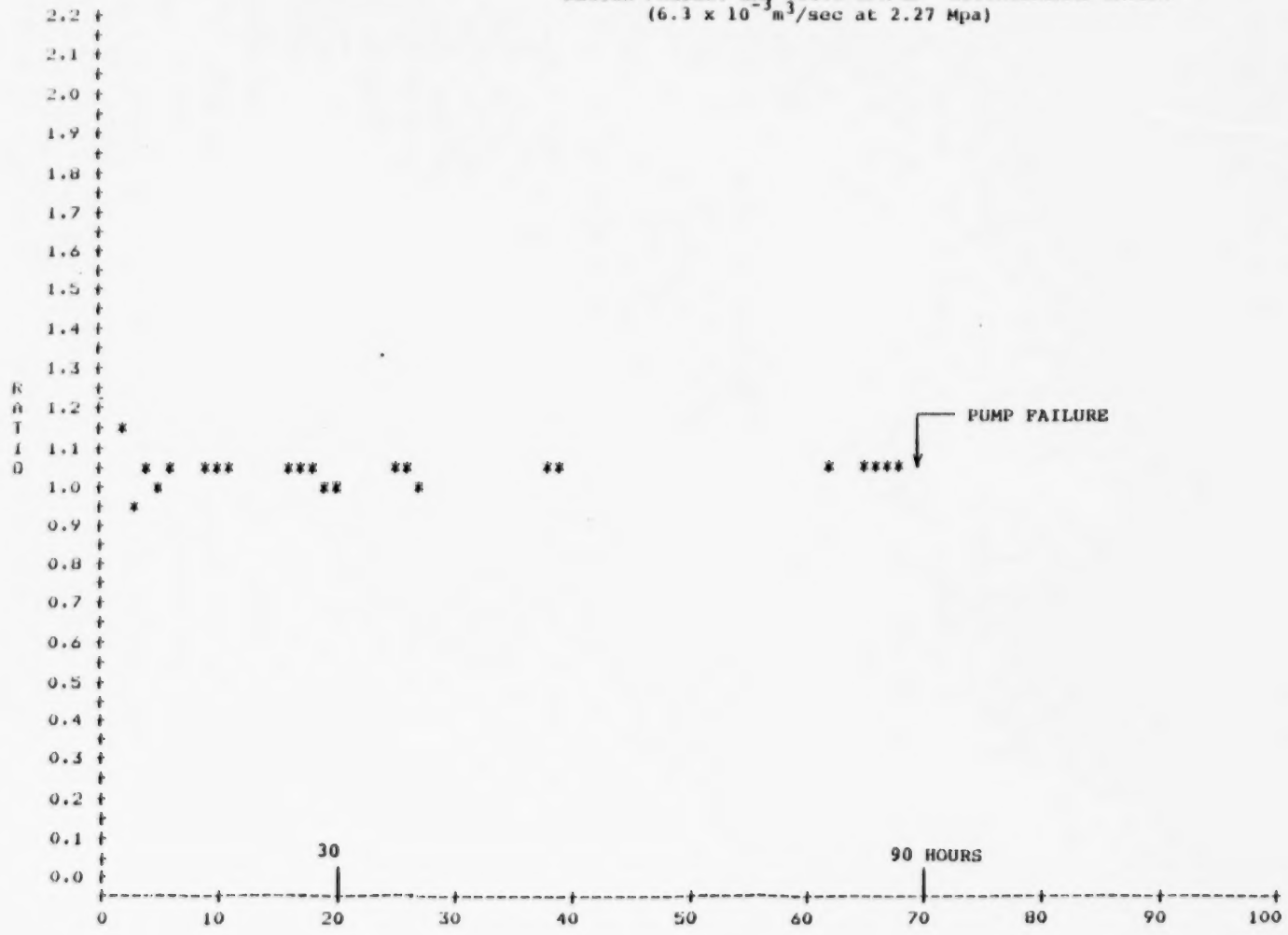
While the 24 hr./day operation was in effect, over 2000 hrs. of operation was generated during the last 300 days of the study.

As can be seen from the data in Figs. 16 through 19, the initiation of the 24 hr./day operation also contributed to increased water usage, thus fouling and flux decline became quite evident. In order to maintain the constant permeate flow of 6.3 x $10^{-3}m^3$/sec @ 75% recovery, it was necessary to increase the operating pressure to approximately 3.79 Mpa. Cleaning the system did not offer any dramatic improvement in the flux rate, but the more frequent cleanings toward the end of the study did aid in maintaining the permeate flow at a respectable level.

Fig. 14 ESCONDIDO JUNE THROUGH AUGUST 1975

RATIO OF NORMALIZED FLOW
TO DESIGN FLOW VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI; AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
(6.3 x 10^{-3} m^3/sec at 2.27 Mpa)



ELAPSED TIME - DAYS

Fig. 15 ESCONDIDO FEB 12 THROUGH MAY 12,1976

RATIO OF NORMALIZED FLOW
TO DESIGN FLOW VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

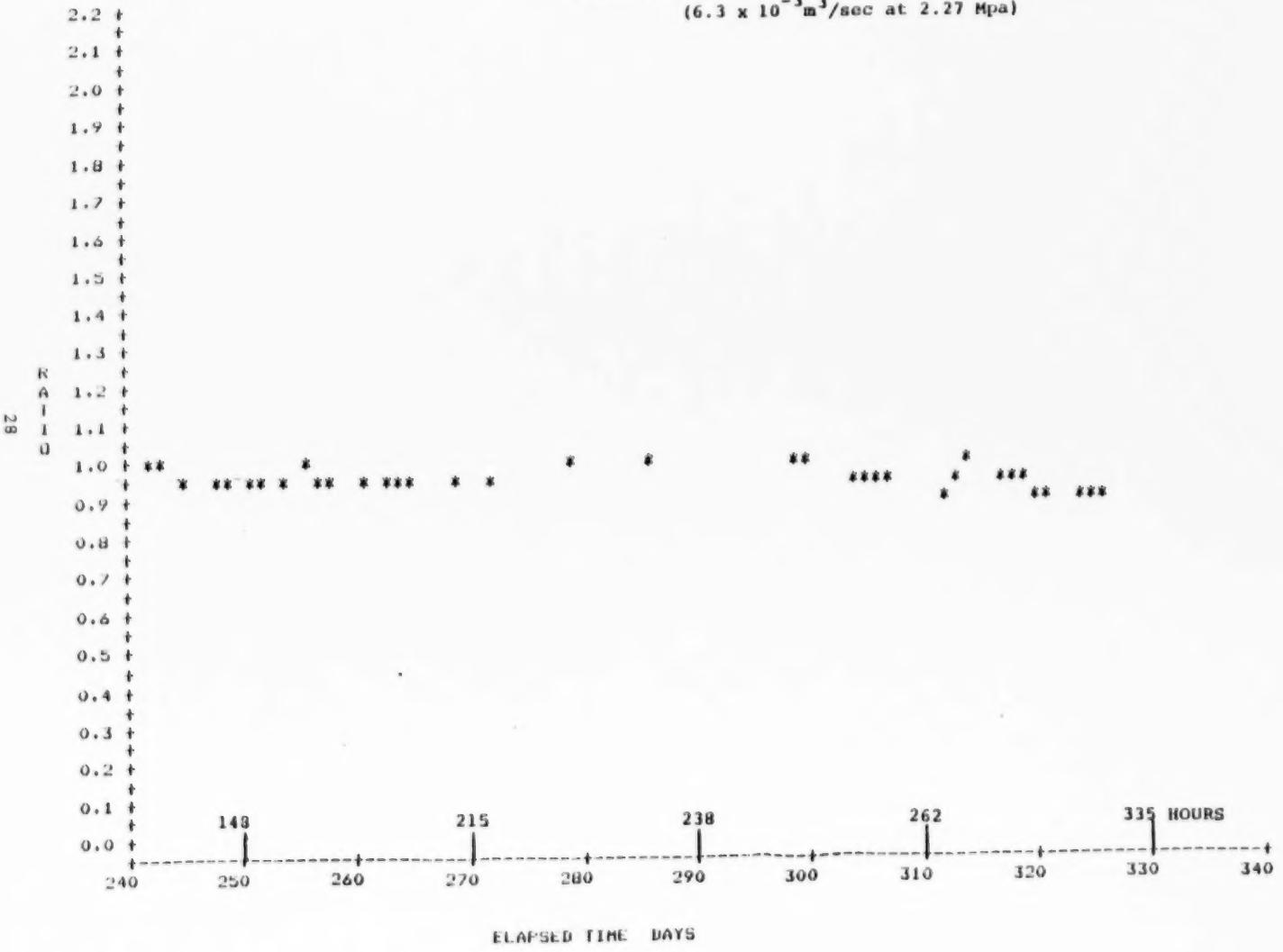


Fig. 16 ESCONDIDO MAY 13-AUG 12,1976

RATIO OF NORMALIZED FLOW
TO DESIGN FLOW VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

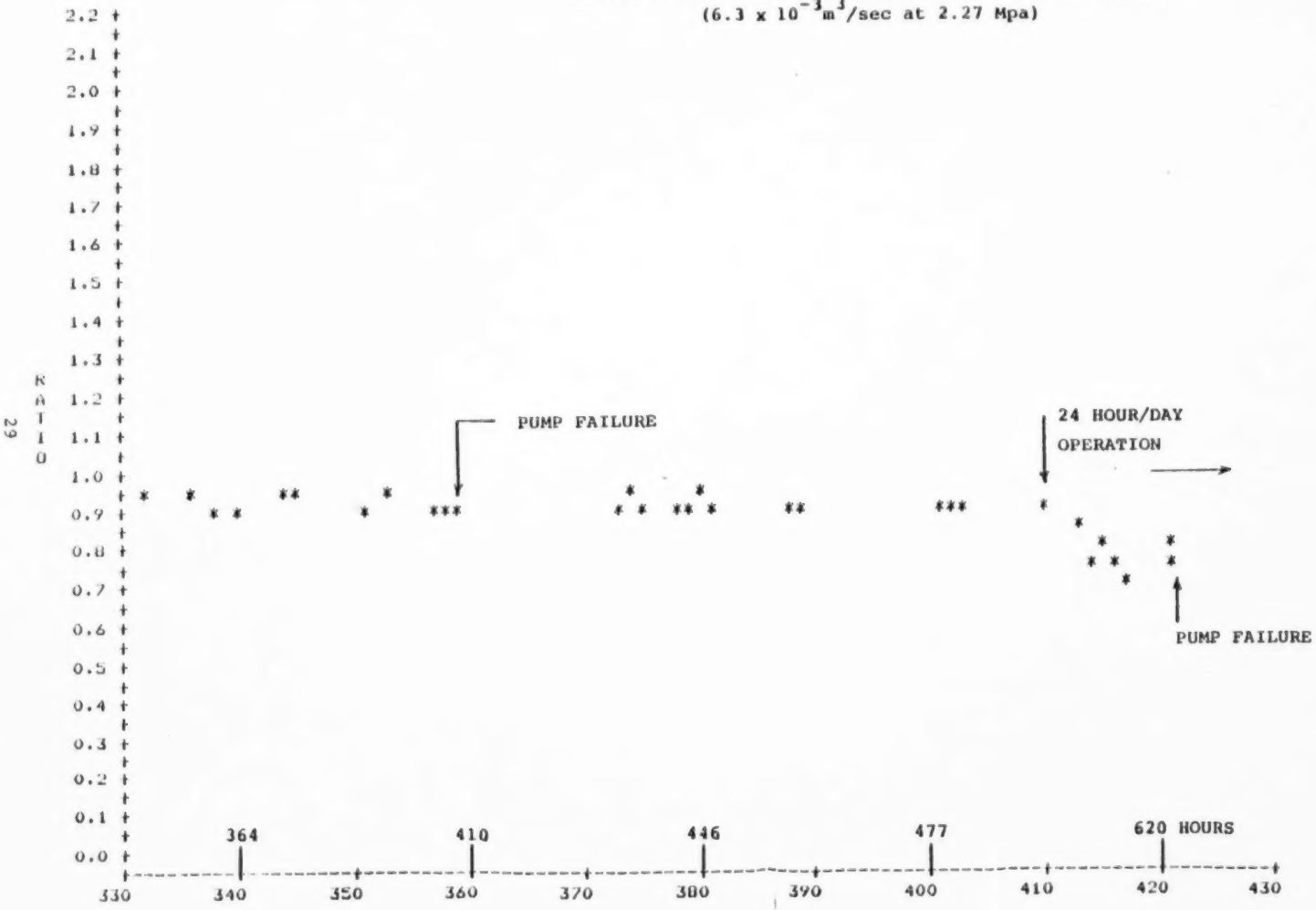


Fig. 17 ESCONDIDO OCT 1 - DEC 31 1975

RATIO OF NORMALIZED FLOW
TO DESIGN FLOW VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
(6.3 x 10 $^{-3}$ m^3/sec at 2.27 Mpa)

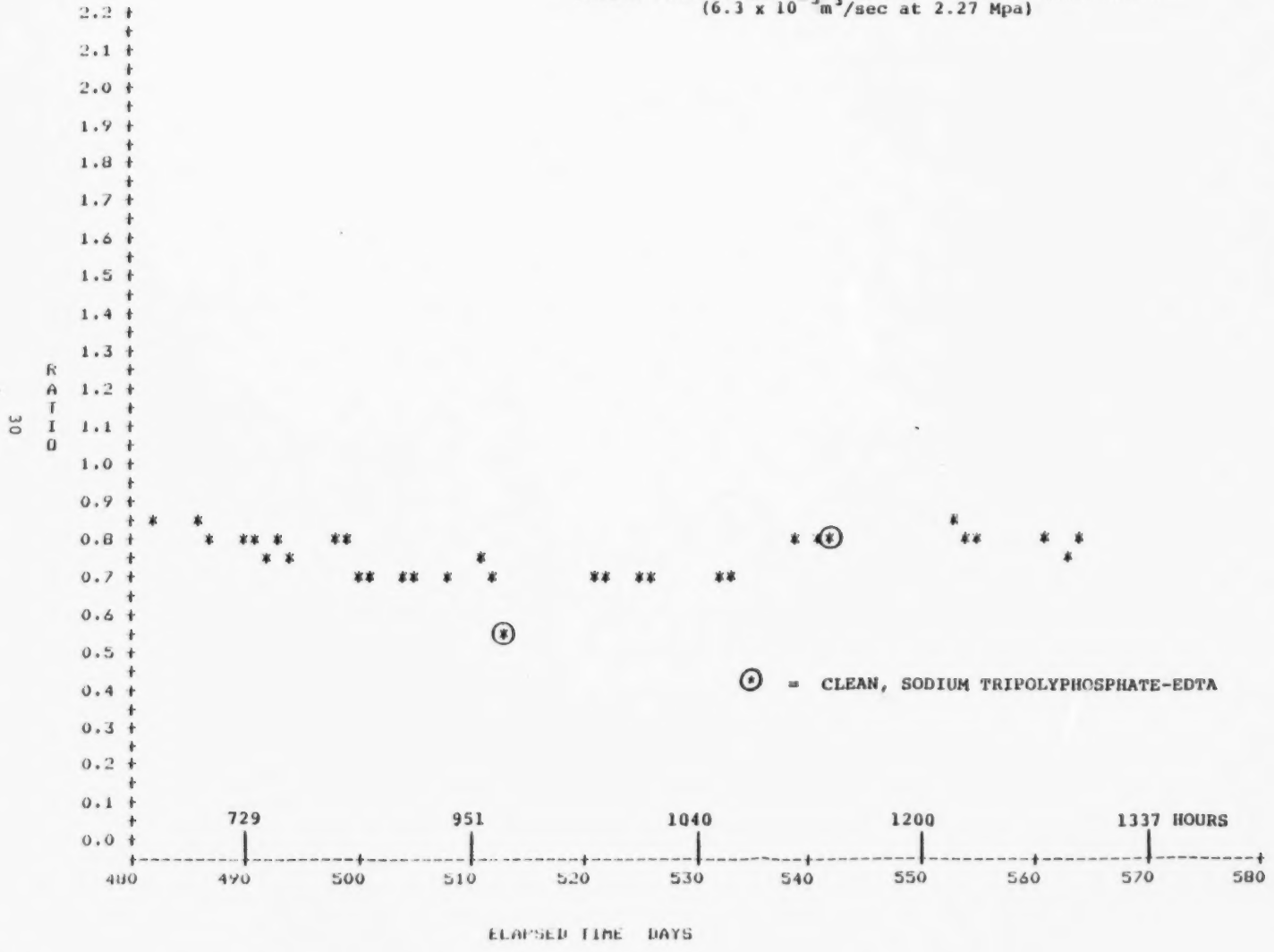


Fig. 18 ESCONDIDO JAN THROUGH MAR 1977

RATIO OF NORMALIZED FLOW
TO DESIGN FLOW VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
(6.3×10^{-3} m^3/sec at 2.27 Mpa)

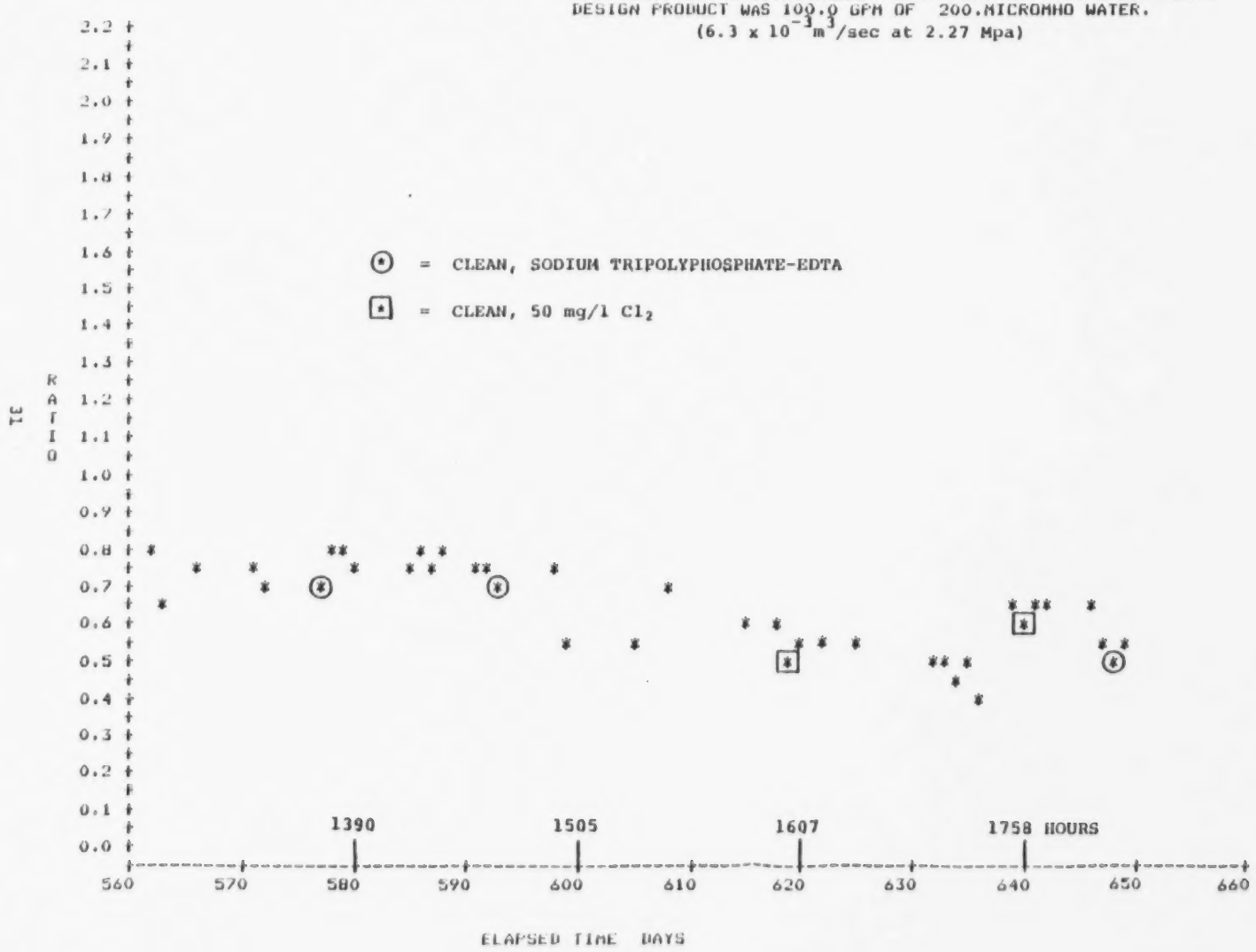


Fig. 19 ESCONDIDO APR THROUGH MAY 27,1977

RATIO OF NORMALIZED FLOW
TO DESIGN FLOW VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
(6.3×10^{-3} m^3/sec at 2.27 Mpa)

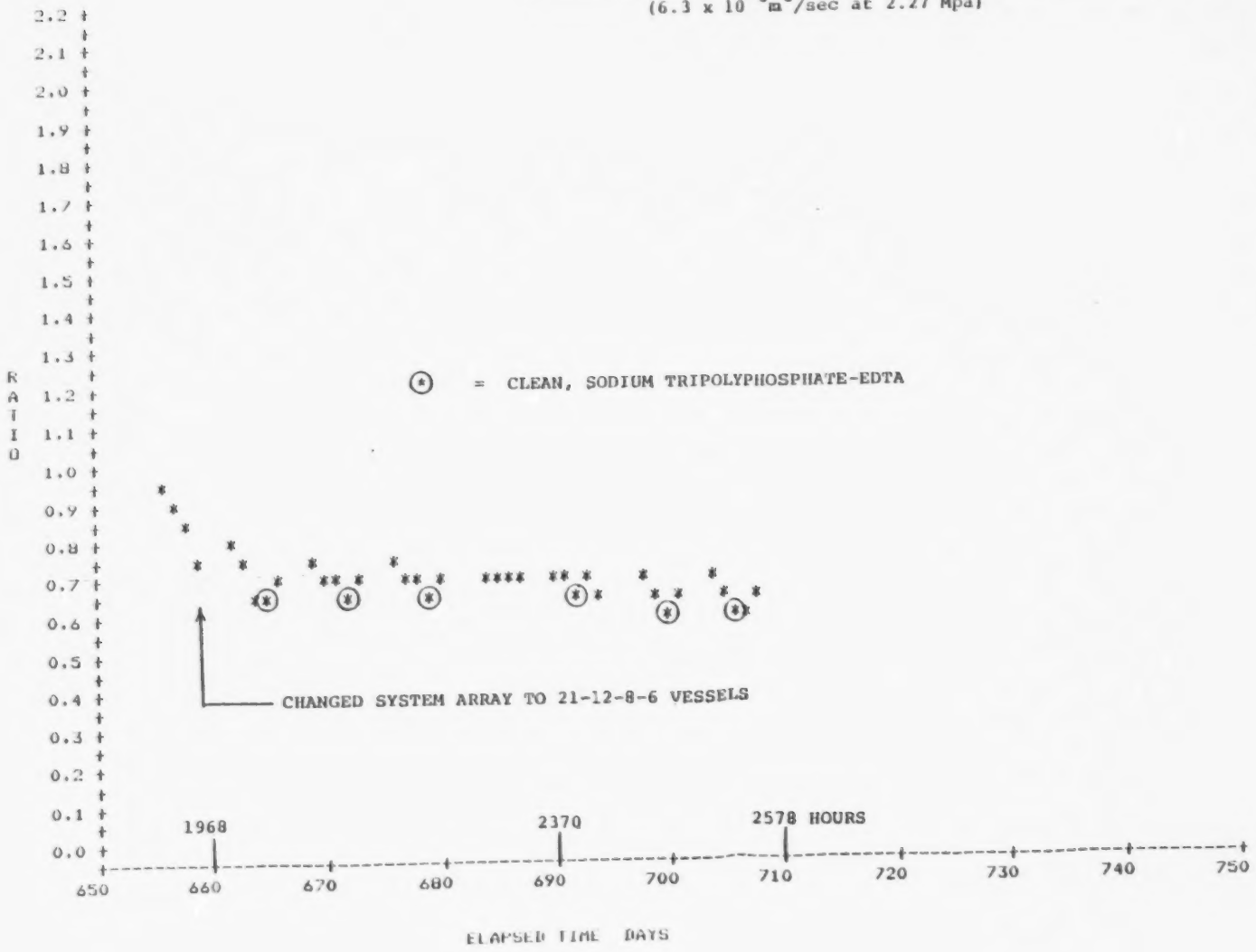


Fig. 20 ESCONDIDO JUNE THROUGH AUGUST 1975

RATIO OF NORMALIZED QUALITY
TO DESIGN QUALITY VS TIME

REFERENCE CONDITIONS WERE;
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY,
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

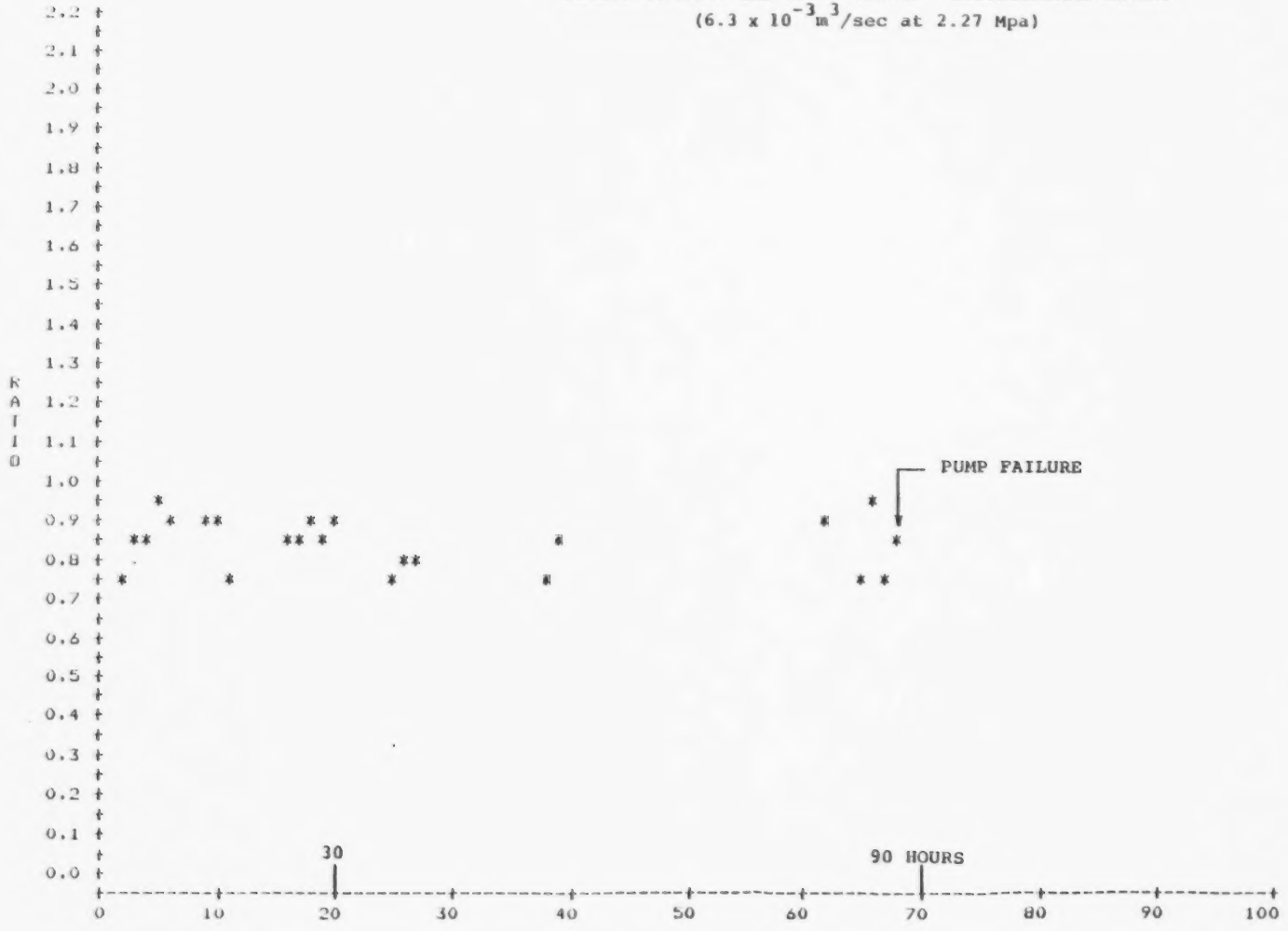


Fig. 21 ESCONDIDO FEB 12 THROUGH MAY 13,1976

RATIO OF NORMALIZED QUALITY
TO DESIGN QUALITY VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

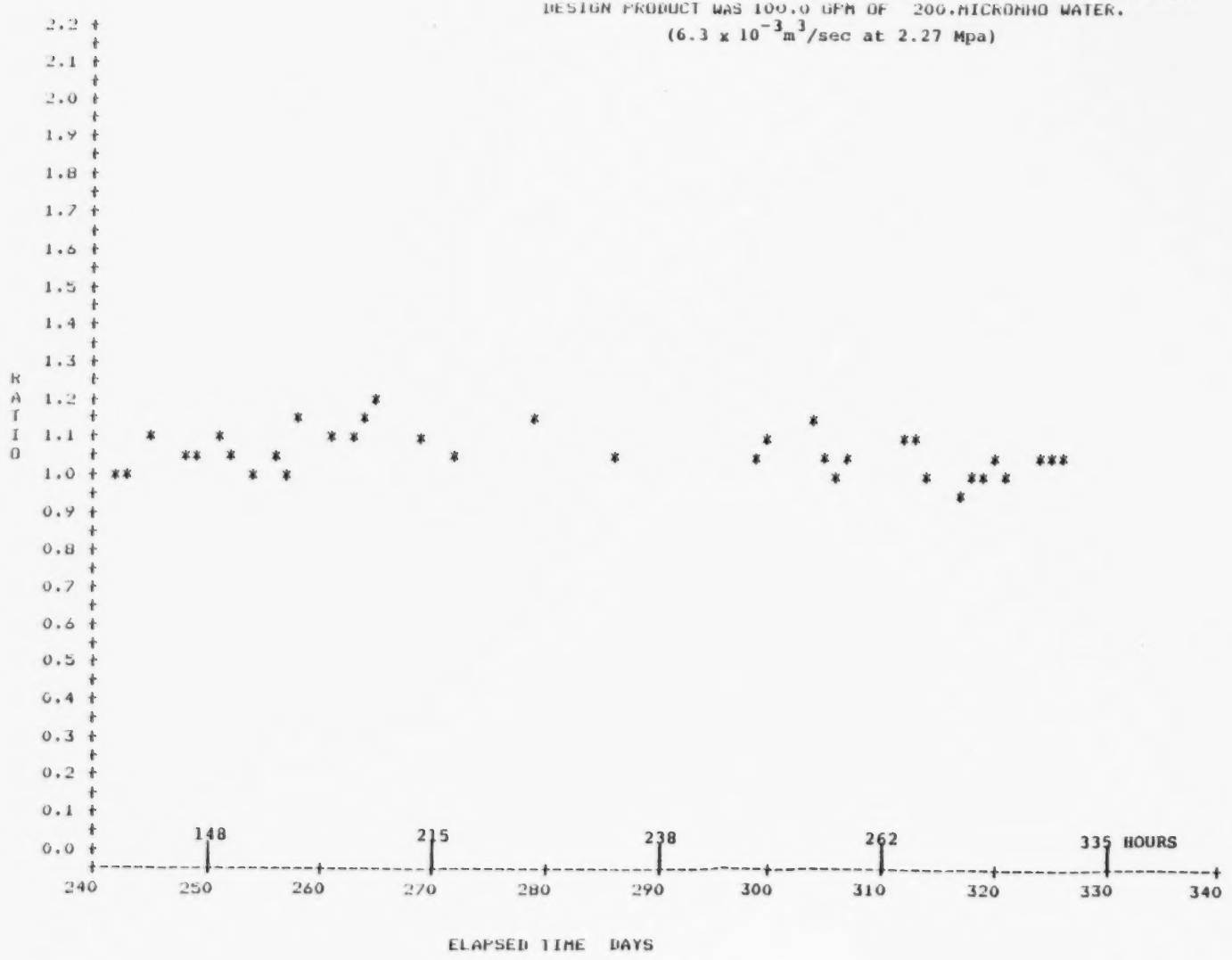


Fig. 22 ESCONDIDO MAY 13-AUG 12,1976

RATIO OF NORMALIZED QUALITY
TO DESIGN QUALITY VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

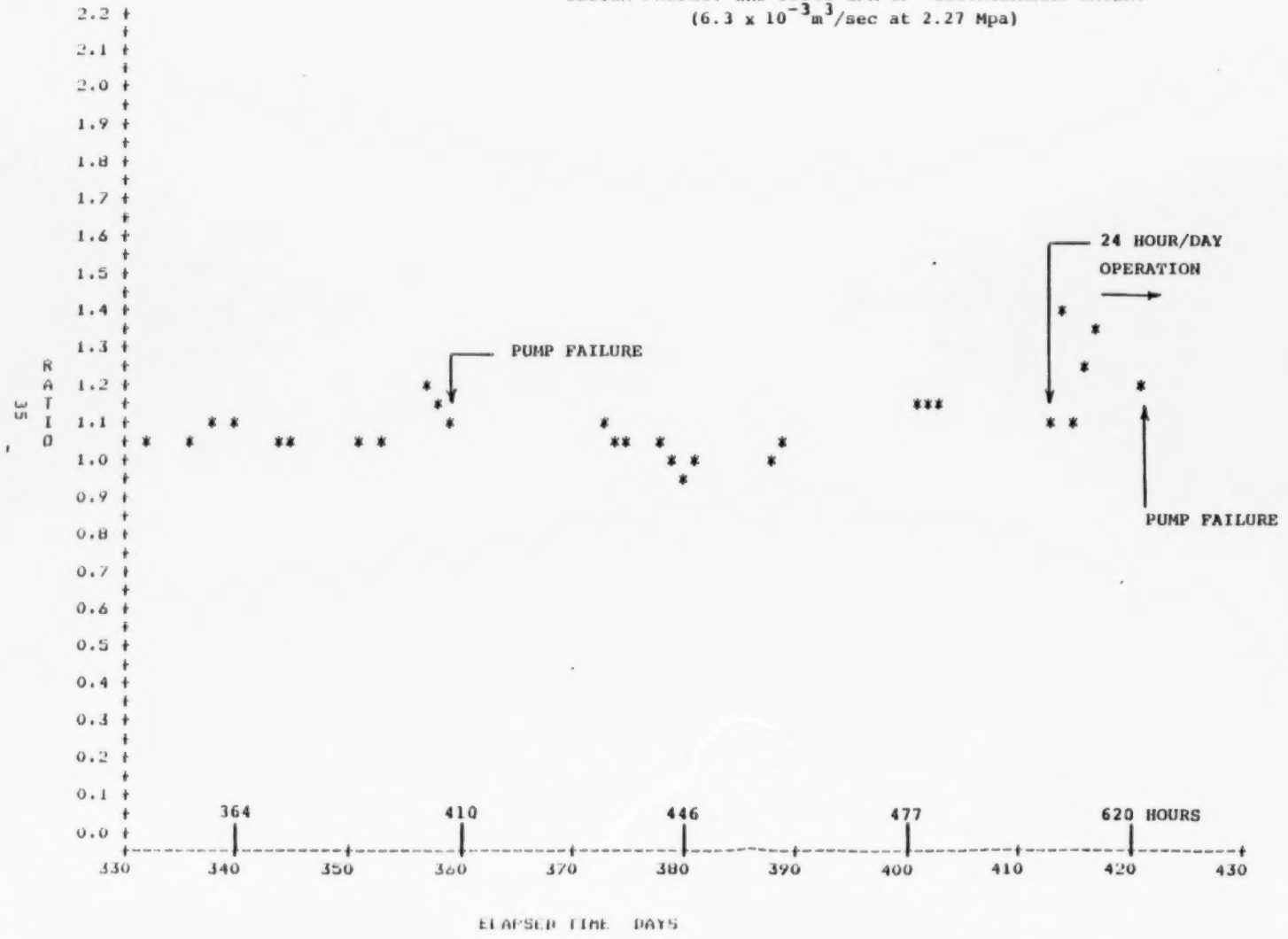


Fig. 23 ESCONDIDO OCT 1 - DEC 31 1975

RATIO OF NORMALIZED QUALITY
TO DESIGN QUALITY VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

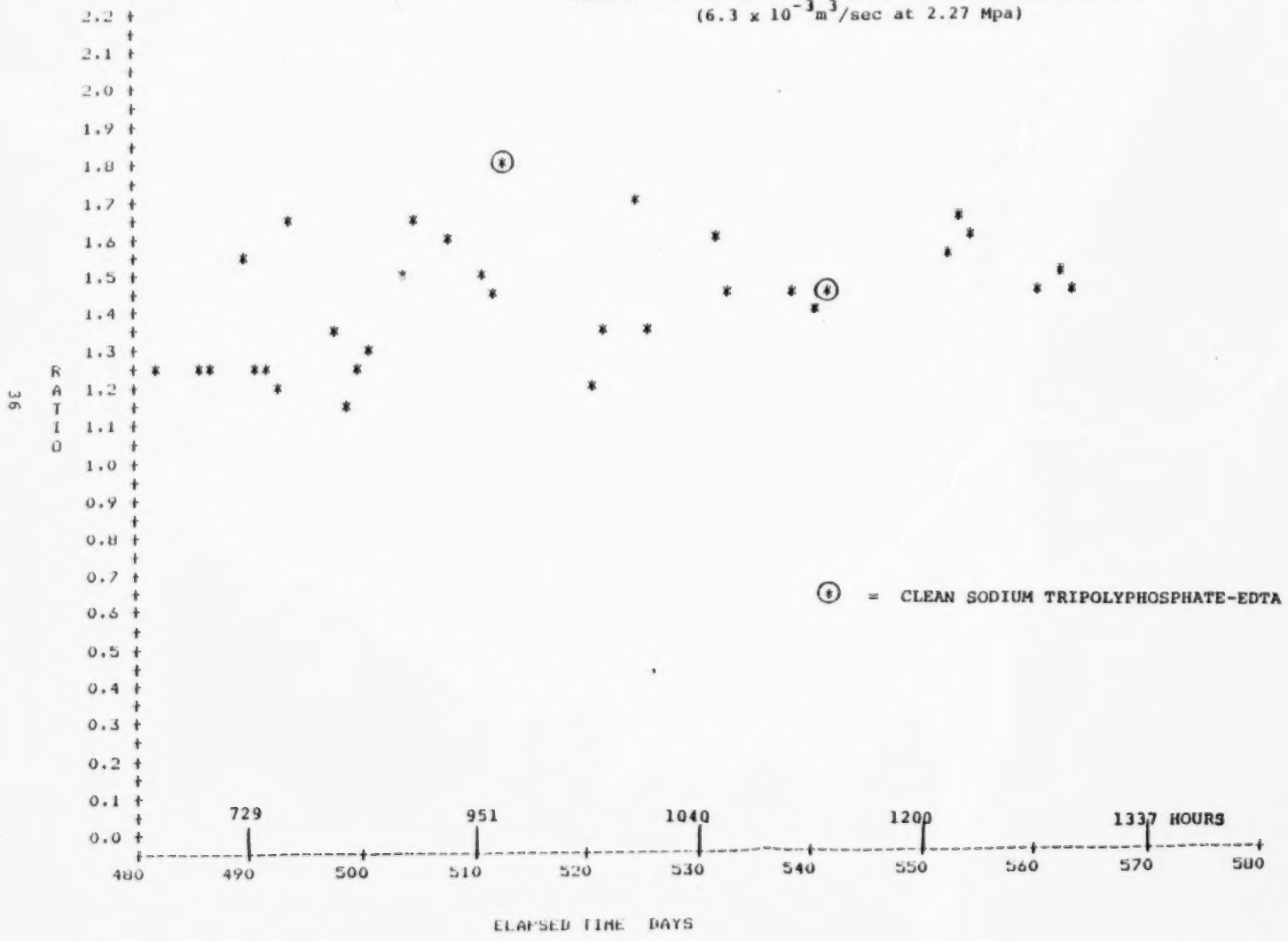


Fig. 24 ESCONDIDO JAN THROUGH MAR 1977

RATIO OF NORMALIZED QUALITY
TO DESIGN QUALITY VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)

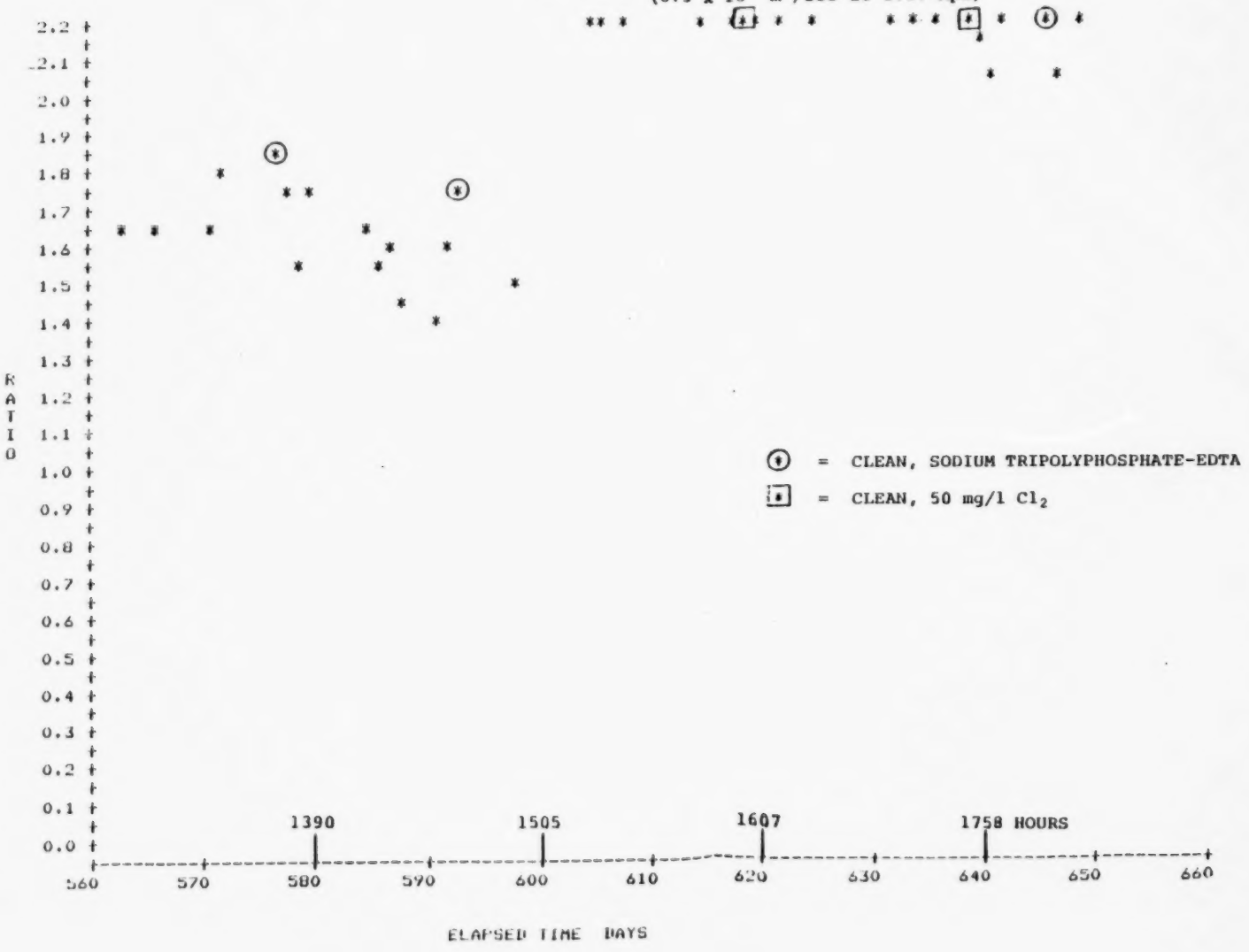
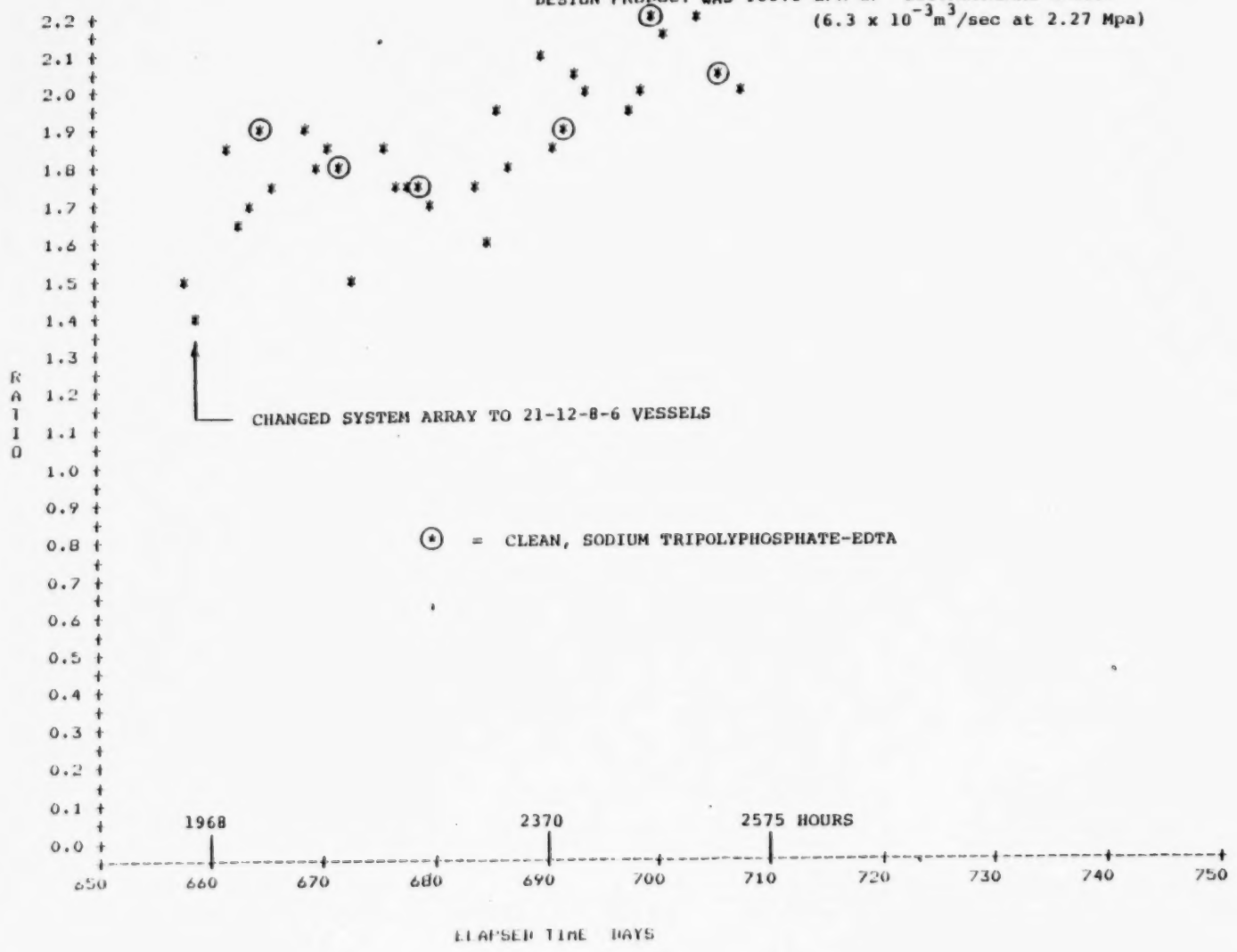


Fig. 25 ESCONDIDO APR THROUGH MAY 27,1977

RATIO OF NORMALIZED QUALITY
TO DESIGN QUALITY VS TIME

REFERENCE CONDITIONS WERE:
FEED 25.0 C, 2500.MICROMHO 330. PSI, AT 75. % RECOVERY.
DESIGN PRODUCT WAS 100.0 GPM OF 200.MICROMHO WATER.
($6.3 \times 10^{-3} m^3$/sec at 2.27 Mpa)



At 1968 hours the elements in the final two passes of the system were removed and replaced. The system was then loaded with 156 new elements and the system was changed from the initial 21-14-10 array @ 75% recovery to a 21-12-8-6 array at the same 75% recovery. It was hoped that by operating in this mode a more stabilized performance could be obtained. This goal was achieved but weekly cleanings were necessary to maintain the flux output. The elements that were removed were heavily fouled with a thick gelatinous deposit that develops when organic materials present in the secondary effluent are concentrated in the final stages of the RO system. This material then becomes a sticky, highly tenacious coating on the membrane surface.

A sample of this material showed a loss of weight on ignition at 600°C of 76.8%, indicating it to be mainly organic. The percent silica was found to be 5.8%. A bead of the dried material gave an infrared spectrum typical of hydroxylated organic acids normally found in the membrane deposits of units run on surface waters and sewage effluents. The material was mostly in the form of a salt with some free acid present. A colorimetric test with sulfanilic acid showed some hydroxylated aromatics but quinone derivatives were not noted with Nile Blue. Treatment with aluminum ion followed by precipitation gave 19.9% insoluble material which could be classified as "humic acid". This is probably a minimum value. This fouling appears to be of the usual type for surface waters and sewage effluents, i.e., deposition of polyvalent salts of complex hydroxyorganic acids as the feed is increasingly concentrated.

The excessive fouling also appears to have contributed to poorer salt rejection because of the increased concentration polarization at the membrane surface. Cleaning the system seemed to improve its salt rejection capability on several occasions, however there were times when cleanings had little or no effect on salt rejection as shown in Figs. 20 through 25. Appendix B is included in this report as a useful means of interpreting the data found in Figs. 14-25.

After approximately 1000 hours of operation, the reverse osmosis system was cleaned for the first time with the cleaning solution developed by Fluid Systems for use with systems fouled with organic material. This is the sodium tripolyphosphate-EDTA cleaner noted in Figs. 14-25. And on two occasions, the system was flushed with 50 mg/l Cl_2 using sodium hypochlorite but with no cleaning success as the data indicates. The more favorable cleaning technique used was the sodium tripolyphosphate-EDTA mixture and that technique is outlined as follows:

1. Cleaning solution - to 1.89m^3 of permeate water the following chemicals are added and mixed with the cleaning pump:

a)	Sodium tripolyphosphate	45.4Kg
b)	Sodium EDTA - 39% solution	37.9 liters
c)	CarboxyMethyl Cellulose (CMC)	25 grams
d)	Triton X-100 Surfactant	500 grams
e)	Formaldehyde (37% solution)	28.5 liters
f)	Sulfuric Acid (H_2SO_4)	3.79 liters

   The above solution has a highly basic pH, however, the acid addition lowers the pH value to 7.5. This solution is heated to 37.8°C and the system cleaning is undertaken.

2. Cleaning sequence - the cleaning sequence used at the Escondido site consisted of passing the cleaning solution through 45 vessels in three separate passes. After the proper valves are set, each vessel is cleaned for 45 minutes at 37.8°C and a maximum flow rate of $3.78 \times 10^{-4} m^3$/sec per vessel.

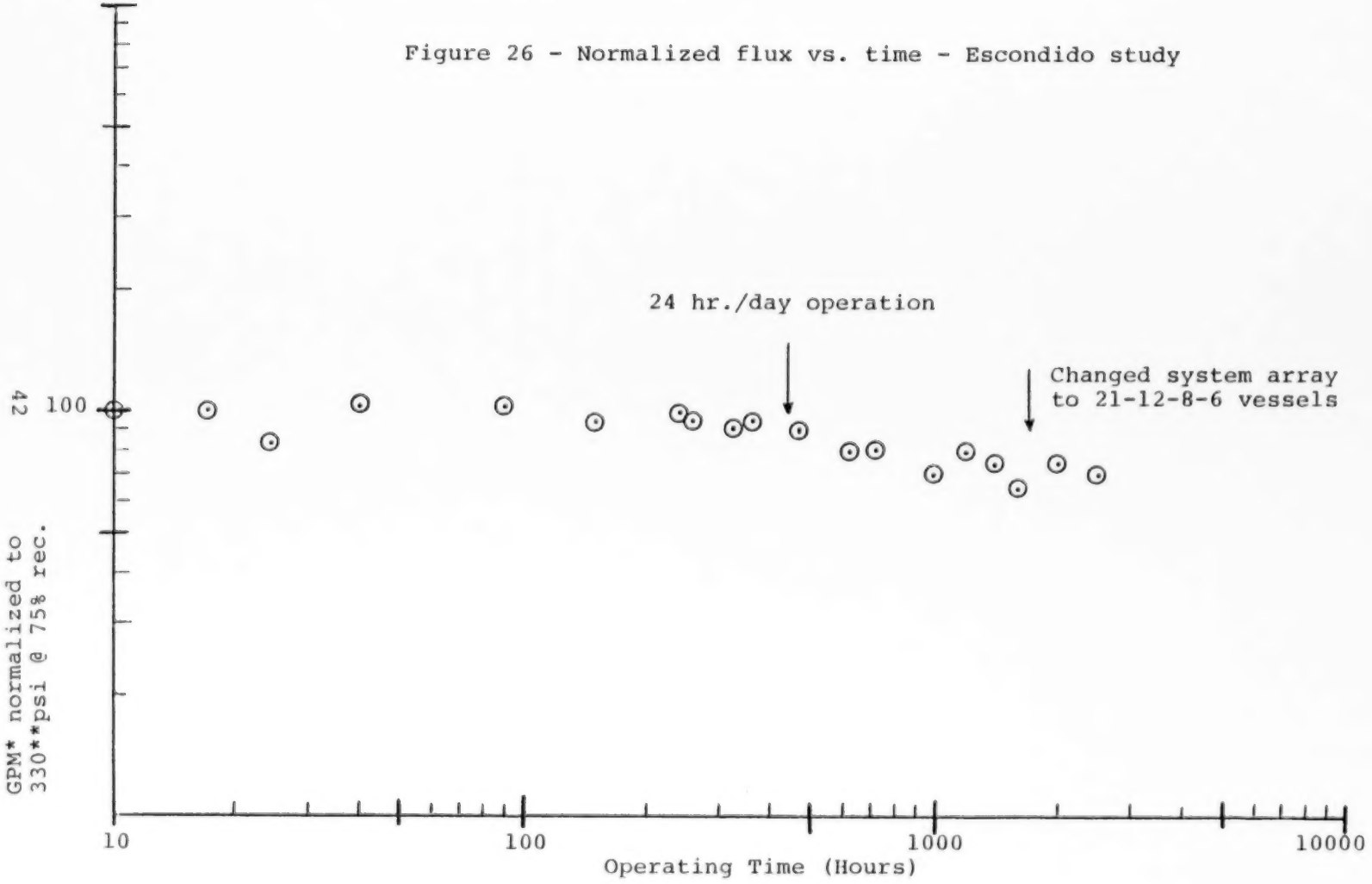
Fig. 26 shows a log-log plot of normalized flux (GPD) vs. time for the Escondido study. The flux decline slope for the first 500 hrs. of the study was calculated with a least squares fit to be m= -0.017. This value is low because of the daily shutdowns and formaldehyde flushes that was the predominate mode of operation during that time span. This type of operation tends to relax the membrane during the shutdown and the formaldehyde flush serves as a cleaner of the membrane surface as well as disinfection; both factors contributing to lessening the flux decline.

At approximately 500 hours, the unit was put on a 24 hr./day operation with less shutdowns and only a once weekly formaldehyde flush for weekend disinfection. The flux decline slope was calculated for the last 2000 hours of the study with a least squares fit to be m= -0.051.

Table 6 shows the effects of pretreatment on the RO feed quality. Acidification of the raw feed (secondary effluent) appears to increase turbidity. Filtration with media and cartridge filters lowers both the turbidity and suspended TOC. Further filtration through 0.45 micron Millipore filters indicates more TOC removal. The TOC differences between unfiltered and filtered samples show considerable organics > 0.45 micron for the raw feed and the RO feed. This may be responsible for much of the turbidity. In the concentrate the turbidity may be caused by particles < 0.45 micron in diameter.

Tables 7-9 show data reductions of dissolved materials over the course of the study. Reverse osmosis membranes have the outstanding capability of selectively transporting water while acting as a barrier to dissolved, colloidal, and suspended solids. In general most of the reductions remained relatively constant during the study. Any decline in reduction is most likely the result of some membrane hydrolysis which would hamper the membrane rejection capabilities.

Figure 26 - Normalized flux vs. time - Escondido study



* 100 GPM=approx. $6.3 \times 10^{-3} m^3/sec$

** 330 psi=approx. 2.27 Mpa

TABLE 6

EFFECTS OF PRETREATMENT ON THE

ESCONDIDO FEEDWATER QUALITY

Sample	Turbidity (NTU)	pH	TOC unfiltered mg/l	TOC filtered mg/l	UV Absorbence 275 nm (filtered)
Raw Feed-A	4.7	7.2	16.7	11.4	0.116
RO Feed-A After Filters	1.9	5.8	16.9	13.4	0.096
Permeate-A	0.12	5.3	4.6	----	0.012
Concentrate-A	6.1	5.8	40.4	40.8	0.089*
Raw Feed-B	2.3	7.3	15.8	13	0.112
After acid, Cl_2-B	5.2				
After stabilization tank-B	7.0		22.8	15.4	0.110
After filters-B	2.1		13.9	13.1	0.111
Permeate-B	0.19		3.8		0.009
Concentrate-B	11		38		0.490
Acidification of raw feed supernatant:					
Raw feed-B	1.4	7.3			
	1.6	5.6			
	2.0	3.2			
	2.0	1.8			

* UV absorbance on 1:4 dilution

TABLE 7

REDUCTION OF FEED SOLUTES AT 75% RECOVERY
ESCONDIDO STUDY, JULY, 1975 UPON START-UP

Constituent	Feed Concentration (mg/l)	Permeate Concentration (mg/l)	Percent Reduction
Calcium Ca	124	< 1.0	> 99.2
Magnesium Mg	34	< 1.0	> 97.1
Sodium Na	312	34	89.1
Potassium K	13	1.2	90.8
Total Hardness $CaCO_3$	450	6.0	98.7
Bicarbonate HCO_3	32	17	46.9
Sulfate SO_4	487	0	100
Chloride Cl	421	31	92.6
Nitrate NO_3 (N)	35	16	54.3
Silica SiO_2	23	3.3	85.7
Iron Fe	0.04	0	100
Manganese Mn	0	0	-
Ortho Phosphate PO_4	16	0.08	99.5
TDS	1400	80	94.3
COD	21	9.5	54.7
Cond. @ 25°C µmhos	2300	178	92.3

TABLE 8

REDUCTION OF FEED SOLUTES AT 75% RECOVERY

ESCONDIDO STUDY, MAY - DEC., 1976

Constituent	Feed [a] Concentration (mg/l)		Permeate [a] Concentration (mg/l)		Percent Reduction [b]
	Average Value	Range	Average Value	Range	
Calcium Ca	121	114-130	1.7	1.2-2.4	98.6
Magnesium Mg	45	36-50	0.49	0-1.0	98.9
Sodium Na	299	288-320	28	20-34	90.6
Potassium K	14.1	11.6-16	1.29	1.0-1.72	90.9
Ammonia NH_4	13.5	13-14	1.3	0.6-2.0	90.4
Total Hardness $CaCO_3$	491	480-500	11.7	8-16	97.6
Bicarbonate HCO_3	100	77-146	19.1	13-24	80.9
Sulfate SO_4	440	419-460	2.5	2-3	99.4
Chloride Cl	454	442-473	42	38-46	91.2
Nitrate NO_3 (N)	16.5	16-17	7.35	6-8.7	55.5
Fluoride F	1.07	0.64-1.5	0.04	0-0.08	96.3
Boron B	0.6	-	0.6	-	0
Silica SiO_2	19	16-22	2.9	2.2-4.2	84.7
Iron Fe	0.08	0.03-0.12	0.25	0-0.5	68.8
Manganese Mn	0.02	0-0.07	0.008	0-0.03	60.0
Total Phosphate PO_4	48	26-70	0.7	0.4-1	98.5
Ortho Phosphate PO_4	12	6-17	0.04	0-0.11	99.7
Susp. Solids	22.1	11.2-33	2.4	0.8-4	89.1
Fixed Susp. Solids	1.1	0-2.4	0.13	0-0.4	88.2
Volatile S.S.	20.5	9-32	2.2	0.4-4	89.3
TDS	1598	1589-1605	100	80-111	93.7
Turbidity NTU's	0.98	0.65-1.3	0.15	0.12-0.17	84.7
Cond. @ 25°C µmhos	2318	2260-2450	216	160-260	90.7
BOD	1.05	1.0-1.1	0	0	100
COD	20	12-28	5	0-10	75

[a] Based on 4 samples

[b] Based on feed

TABLE 9

REDUCTION OF FEED SOLUTES AT 75% RECOVERY

ESCONDIDO STUDY, JAN. - MAY, 1977

Constituent	Feed [a] Concentration (mg/l)		Permeate [a] Concentration (mg/l)		Percent Reduction [b]
	Average Value	Range	Average Value	Range	
Calcium Ca	119	92-156	1.56	1-2.4	98.7
Magnesium Mg	49.1	40-67	2.15	1.5-2.8	95.6
Sodium Na	257	195-294	33.7	28-46	86.9
Potassium K	15	13.7-18	2.35	2.05-2.8	84.3
Ammonia NH_4	7.1	4-11	1.25	0.7-1.6	82.4
Total Hardness $CaCO_3$	489	470-510	13	12-14	97.3
Bicarbonate HCO_3	63.8	42.9-105	11.3	8.9-12.8	82.3
Sulfate SO_4	423	399-439	1	0.5-5.1	99.8
Chloride Cl	407	355-466	38.5	33.6-49	90.5
Nitrate NO_3 (N)	25.9	18.5-32	9.58	6.8-11.7	63.0
Fluoride F	5.08	3.7-6.6	0.36	0.2-0.61	92.9
Boron B	0.8	0.5-1.3	0.56	0.3-0.8	30.0
Silica SiO_2	11.3	4-16	1.5	1-2	86.7
Iron Fe	0.05	0.02-0.07	0.01	0-0.02	80.0
Manganese Mn	0.07	0.03-0.11	0.004	0-0.01	94.3
Total Phosphate PO_4	25	17-32	0.05	0.02-0.08	99.8
Ortho Phosphate PO_4	17.4	10-22	0.006	0-0.02	99.9
Susp. Solids	8.1	6-9.6	0.6	0.2-1.0	92.6
Fixed Susp. Solids	1.8	0.8-3.8	0.033	0-0.2	98.2
Volatile S.S.	5.66	5-6.2	0.33	0.2-0.6	94.2
TDS	1550	1456-1628	128	101-164	91.7
Turbidity NTU's	1.67	0.92-2.8	0.2	0.11-0.38	88.0
Cond. @ 25°C µmhos	2238	2100-2350	268	242-300	88.0
BOD	1.38	0-4.3	0		100
COD	31.9	20.8-38	4.07	0-9.4	87.2

(a) Based on 6 samples

(b) Based on feed

A more complete analysis was also done on RO permeate samples taken in July, 1975. This study was done by Gulf South Research Institute (New Orleans, La.) for a report submitted to the EPA. Table 10 shows the results of this analysis with a comparison of performance vs. compliance to drinking water standards. Their findings also indicated the following in the tests for enteric viruses:

BGM[1] test = 0 pfu.[3]
PMK[2] test = 0 pfu.[3]

The reverse osmosis membrane acts as an absolute particulate filter and reverse osmosis systems can be used to prepare particulate - free water for industry. The data presented in Tables 7-10 indicates the reclaimed water is of high quality and requires little or no treatment for most domestic, commercial, industrial, and agriculture uses. The water as produced is weakly acidic and unbuffered. The pH can be adjusted to neutral with decarbonation and small amounts of lime, caustic, or calcium carbonate. Feed water is chlorinated to control fouling and biological growths in the system feed channels. Activated carbon and/or aeration can be used to remove residual organics from the permeate. These tests have shown that the reverse osmosis permeate from most waste water effluents has a lower organic content than any produced by conventional treatment processes. However, disinfection of the permeate is required as a safety precaution. Since major interferences to chlorination and disinfection are removed to a great extent by reverse osmosis, the product is easily disinfected.

1 Buffalo Green Monkey (culture test for virus)
2 Primary Monkey Kidney (culture test for virus)
3 Plaque Forming Unit

Table 10

Comparison of Escondido R.O. Permeate

to Drinking Water Standards

Parameter	Drinking Water Standard	Escondido Permeate
Physical		
Color	15 CU	1 CU
Odor	3 TON	14 TON
Turbidity	1 JTU	0.8 JTU
Microbiological		
Total Coliform	1/100 ml	0
Chemical		
Ammonia (as N)	0.5 mg/l*	1 mg/l
Arsenic	50 µg/l	ND**
Barium	1000 µg/l	ND
Cadmium	10 µg/l	ND
Carbon Chloroform Extract (CCE)	700 µg/l	-
Chloride	250 mg/l	24.3 mg/l
Chromium (+6)	50 µg/l	ND
Cyanide	200 µg/l	0.06 µg/l
Copper	1000 µg/l	10 µg/l
Fluoride	1.4-2.4 mg/l	0.3 mg/l
Iron	300 µg/l	20 µg/l
Lead	50 µg/l	ND
Manganese	50 µg/l	ND
Mercury	2 µg/l	0.3 µg/l
Nitrates (as N)	10 mg/l	9 mg/l
Phenols	1 µg/l	7.4 µg/l
Selenium	10 µg/l	180 µg/l

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Table 10 (Continued)

Comparison of Escondido R.O. Permeate

to Drinking Water Standards

Parameter	Drinking Water Standard	Escondido Permeate
Silver	50 µg/l	0.2 µg/l
Sulfate	200 mg/l	1.6 mg/l
TDS	500 mg/l	82 mg/l
Zinc	5000 µg/l	20 µg/l
Pesticides		
Aldrin	1 µg/l	ND
Chlordane	3 µg/l	ND
DDT	50 µg/l	ND
Dieldrin	1 µg/l	ND
Endrin	0.2 µg/l	ND
Heptachlor	0.1 µg/l	ND
Lindane	4 µg/l	ND
Methoxychlor	100 µg/l	ND
Herbicides		
2, 4-D	100 µg/l	ND
2, 4, 5-TP Silvex	10 µg/l	ND

* Permissible criteria for Public Water Supplies from National Interim Primary Drinking Water Regulations, December 24, 1975, Environmental Protection Agency, Office of Water Supply, Washington, D. C.

** ND - None detected.

Summary, Conclusions, and Recommendations

The chronology of the program is, unfortunately, in large part a saga of pump problems which were never even considered as part of the program objectives. They arose in large part from the circumstances prevailing in 1974 which forced the decision to utilize the very high speed untried pumps because of unacceptable delivery problems with the preferred pumps at the time. This problem was aggravated by the differing expectations of the parties as to their operational obligations, particularly with respect to those necessary to insure sufficient available operator attention for sustained running of the equipment as originally supplied, and particularly with respect to operating techniques at the treatment plant (oxidation pond), with a reverse osmosis unit downstream. In the course of earlier operations at Pomona and Santee, high levels of turbidity and suspended solids were rare. These were a frequent occurrence at this site (Escondido).

It is recognized that the quality of secondary effluent will vary widely, both between plants and over the course of any one day in some installations. Thus a general purpose recommendation would include a polishing clarifier (with a short detention time of approximately 15-30 minutes) permitting added treatment with iron or alum and polyelectrolyte at a level of a few mg/l. This should be followed by a sectioned multi-media (anthracite, sand, etc.) gravity or pressure filter, then followed by the reverse osmosis system, including pH control, inhibitor, etc.

During this period Fluid Systems sold, installed, and started a $0.22 m^3$/sec system, operating at 85% water recovery to Orange County Water District to operate on pretreated secondary effluent. The cost of that System, sold in 1974 was $132.00 per installed cubic meter (based on purified water output). Today, taking into account inflation, such systems would sell for between $174.00 - $290.00 per installed cubic meter depending on the pretreatment

included, size, recovery, etc. The Orange County unit was also guaranteed as to membrane replacement (based on a 3 year life) and power and chemicals utilization. Membrane replacement costs are estimated to be in the range of $0.034 - $0.053 per cubic meter of purified water recovered. Power utilization is less than 1.58 kilowatt hours per cubic meter of purified water recovered, for systems operating in the temperature range of 15^{o}-30^{o}C at 2.75 - 4.13 Mpa.

Although the experience at Escondido was severly limited as discussed earlier, it is consistent with the above cost numbers. In fact, in a properly organized operation, attending labor will average 2-4 hrs. per shift; there would be adequate pretreatment as indicated by the inclusion of a small polishing clarifier at trivial added expense. Membrane lifetimes at Escondido were confounded by the pump and organizational problems. The experience and lessons learned provide a valid expectancy of 3 year lifetimes and the corresponding economics.

Our recommendation is that considering the money already invested, and the other facts accumulated in similar applications concurrently, that the system be used in a better planned one year program at an appropriate site, with some minimal added pretreatment and features for unattended operation. Thereby the very necessary demonstration of continuous day-in day-out sustained performance would be achieved. The system can also be loaded with new membranes which can operate at lower pressures (lower power consumption), and which are less pH sensitive so that more effective cleaning agents can be tested and proved out.

APPENDIX A

CONVERSION TABLE

Listed below are approximate Metric to U. S. Customary units which are used in this report:

$0.044 - 4.4 m^3/sec = 1 - 100$ mgd

$4.38 - 8.76 \times 10^{-3} m^3/sec = 100{,}000 - 200{,}000$ gpd

$1.3 \times 10^{-2} m^3/sec = 300{,}000$ gpd

$6.57 \times 10^{-3} m^3/sec = 150{,}000$ gpd

$2.07 - 4.14$ Mpa $= 300 - 600$ psi

$6.1 - 7.56 \times 10^{-3} m^3/sec = 97 - 120$ gpm

$8.19 - 9.13 \times 10^{-3} m^3/sec = 130 - 145$ gpm

$28.4 m^3 = 7500$ gal.

$8.82 \times 10^{-3} m^3/sec = 140$ gpm

1.83m $= 6$ ft.

$2.6 m^2 = 28$ ft.^{2}

$4.6 \times 10^{-3} m^3/sec = 73$ gpm

$27.6 - 31$ Kpa $= 4 - 4.5$ psi

103.4 Kpa $= 15$ psi

$1.76 \times 10^{-2} m^3/sec = 280$ gpm

$5.29 \times 10^{-3} m^3/sec = 84$ gpm

$21.2 m^3 = 5600$ gal.

10.16 cm $\times$ 6.096 m $= 4$ in. $\times$ 20 ft.

1.02 m $= 40$ in.

0.69 Mpa $= 100$ psi

$1.893 m^3 = 500$ gal.

$4.62 \times 10^{-3} m^3/sec = 73.5$ gpm

4.47 Mpa $= 650$ psi

$6.3 \times 10^{-3} m^3/sec = 100$ gpm

3.79 Mpa $= 550$ psi

45.4Kg $= 100$ lbs.

37.9 liters $= 10$ gal.

28.5 liters $= 7$ gal.

3.79 liters $= 1$ gal.

$3.78 \times 10^{-4} m^3/sec = 6$ gpm

$0.22 m^3/sec = 5$ mgd

$m^3 = 264$ gal.

$2.75 - 4.13$ Mpa $= 400 - 600$ psi

APPENDIX B

Interpretation of the Graphic Output from the System Monitoring Program

The performance of any given reverse osmosis unit under normal conditions depends primarily on net driving pressure, feed water composition, feed water temperature and recovery rate. These factors are subject to significant variability during the normal course of operations. The unit performance data must be normalized to a set of standard conditions if this data is to be used to reveal subtle undesirable changes or trends. Early recognition of these changes provide the opportunity for corrective action before the problem becomes incurable. In general, the trends shown in the graph are more significant than the absolute value. The following paragraphs describe briefly the graphic presentation of unit performance developed by Fluid Systems' Technical Services Group.

Ratio of Normalized Quality to Design Quality Versus Time

The quality of purified water is normalized to the reference conditions of net driving pressure, feed water composition and recovery rate. The data is then plotted as the ratio of the normalized quality to the reference quality. It is anticipated that at unit start-up, the ratio will be 1.0 or less and will increase gradually with time. The normalized quality can be obtained at any point in time by multiplying the value of the ratio by the design quality which is shown at the top of the graph.

Ratio of Normalized Flow to Design Flow Versus Time

Unit flow data is normalized to the reference conditions of net driving pressure, feed water composition, temperature and recovery rate. The data is then plotted as the ratio of normalized flow to design flow. As in the case of water quality, the initial ratio value at start-up will be approximately 1.0. However, the ratio will decrease gradually with time unlike the time projection of water quality, which increases. The normalized flow can be obtained at any point in time by multiplying the value of the ratio by the design flow which is shown at the top of the graph.